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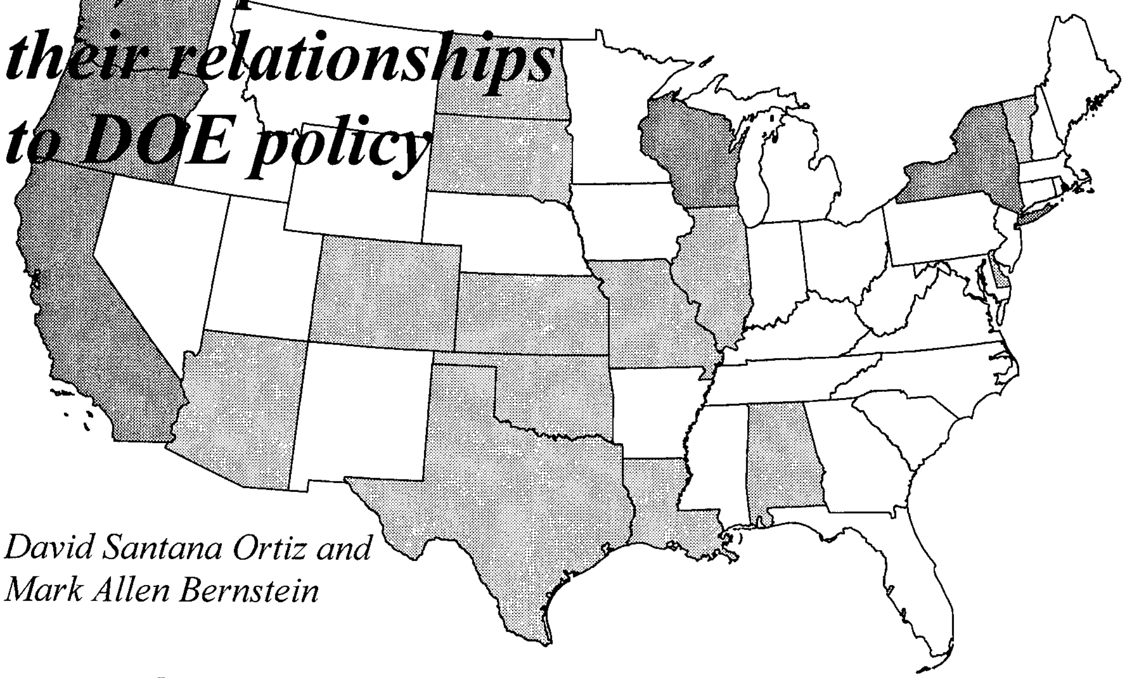
Measures of residential energy consumption and their relationships to DOE policy



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MR-1105.0-DOE

November 1999

Prepared for the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
and the
Office of Science and Technology Policy

This is the final report of a project. It has been formally reviewed but has not been formally edited.

Science and Technology Policy Institute

Preface

The U.S. Department of Energy compiles, analyzes and disseminates data and information on energy use. Their purpose is to answer questions that range from the straightforward in concept – how much foreign oil does the U.S. consume annually? – to the complex – what is the interplay between the energy consumed during mechanical removal of moisture in a washing machine versus its thermal removal in a clothes dryer? Each calculation depends upon a measurement of energy, be it barrels of oil, kilowatt hours of electricity or cubic feet of natural gas.

Every measurement carries with it a degree of uncertainty and possibility for bias. The natural gas and electricity industries claim that the measurement of energy has the potential to influence the market for their products. The question for this report is whether the measurement of energy consumption at the point of use, or at the point of generation or extraction carries with it a bias toward one fuel or another.

This report investigates the impact of measuring energy use either at the point of use or the point of generation on energy use in the residential sector. The issue of whether the measurement basis has an impact on energy use patterns has simmered since the passage of the first national energy legislation in the 1970s and continues today.

This report has been prepared at the request of the DOE's Office of Energy Efficiency and Renewable Energy. The results should be of interest to policymakers and energy suppliers who have been concerned about any possible biases related to energy use, as well as to manufacturers, builders, and homeowners who must comply with appliance standards and home energy codes.

The authors would like to thank those individuals and organizations who helped in the researching and preparation of the report. A partial listing includes the many of the staff of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy; Arthur D. Little, Inc.; Dr. James McMahon and his staff at the Lawrence Berkeley National Laboratory; the stakeholders who provided comments on the issue including Mark Krebs of the LaClede Gas Company and Steve Rosenstock of the Edison Electric Institute, representatives of the American Gas Association, the American Gas Cooling Center, the Edison Electric Institute, the American Refrigeration Institute, Virginia Power, and the Southern Company; Susan Freedman of the Building Codes Assistance Project; Hewan Tomlinson of D&R International; William Prindle of the Alliance to Save Energy; G. William Pennington of the California Energy Commission; Christine Egan of the American Council for an Energy-Efficient Economy; and RAND's internal and external reviewers of the report.

This research was undertaken as a project of RAND's Science and Technology Policy Institute. Originally created by Congress in 1991 as the Critical Technologies Institute and renamed in 1998, the Science and Technology Policy Institute is a federally-funded research and development center sponsored by the National Science Foundation and managed by RAND. The Institute's mission is to help improve public policy by conducting objective, independent research and analysis on policy issues that involve science and technology. To this end, the Institute:

- Supports the Office of Science and Technology Policy and other Executive Branch agencies, offices, and councils
- Helps science and technology decisionmakers understand the likely consequences of their decisions and choose among alternative policies
- Helps improve understanding in both the public and private sectors of the ways in which science and technology can better serve national objectives.

Science and Technology Policy Institute research focuses on problems of science and technology policy that involve multiple agencies. In carrying out its mission the Institute consults broadly with representatives from private industry, institutions of higher education, and other nonprofit institutions.

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List of Acronyms

AGA	American Gas Association
ANOPR	Advance Notice of Proposed Rulemaking
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BCAP	Building Codes Assistance Project
Btu	British Thermal Unit
CABO	Council of American Building Officials
CEC	California Energy Commission
DOE	U.S. Department of Energy
EEI	Edison Electric Institute
EERE	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
EF	Energy Factor
EPA	Energy Policy Act
EPACT	Energy Policy Act of 1992
EPCA	Energy Policy Conservation Act
EIA	U.S. Department of Energy, Energy Information Administration
FEMP	Federal Energy Management Program
FTC	Federal Trade Commission
GSP	Gross State Product
HERS	Home Energy Rating System
ICC	International Code Commission
IECC	International Energy Conservation Code
LBNL	Lawrence Berkeley National Laboratory
MEC	Model Energy Code
MPG	Miles per Gallon
NAECA	National Appliance Energy Conservation Act
NECPA	National Energy Conservation Policy Act
NOPR	Notice of Proposed Rulemaking
OBT	U.S. Department of Energy, Office of Building Technologies
OCS	U.S. Department of Energy, Office of Codes and Standards
OTA	Office of Technology Assessment

Summary

Measurements tend to be viewed as absolutes. The distance from Los Angeles to Washington, DC via major roads and interstate highways is 2674.6 miles according to a popular internet mapping service. But an airline credits 2288 miles to its travelers for the same journey - 14.5 percent fewer miles. The distance measurement is a function of the mode of transportation: the airplane can fly a straight line whereas the interstate highway system constrains the car's motion. Also, embedded in the measurement are assumptions regarding the route and altitude. In short, measurements and their meanings depend on context and purpose.

Another measure of the same journey is the fuel use per passenger. For the automobile, the total gallons of gasoline or the total gallons of gasoline per passenger would be convenient measures. Were consumer cost or convenience a primary concern, the cost per person or the elapsed time of the trip may be more important. Similar metrics could be applied to air travel so that the appropriate comparison could be made. Even with accurate data regarding the metrics above, no two trips would require the same amount of fuel, cost the same amount of money or take, the same amount of time. There are too many exogenous inputs: the traffic, the speed, the choice of roads, the wind, etc. Travelers have grown accustomed to these uncertainties.

The U.S. Department of Energy (DOE) faces similar problems with respect to the measurement of energy. The same household appliance can use significantly different amounts of energy depending on the user, the geographic location in which it is installed, and the level of maintenance that the owner provides. Despite these differences, the DOE develops test procedures to measure the energy consumption of the appliance and support the promulgation of minimum efficiency standards for appliances. The DOE and the Federal Trade Commission (FTC) label appliances with the information from the test procedure, the energy use, and the estimated costs of operation.

There are those who argue that the DOE test procedures are flawed in concept: the DOE test procedures for appliances measure the energy consumed at the point of use. However, there are significant losses of energy due to the extraction, generation,

transmission and distribution of the energy from the source to the end user; the losses can add to 70 percent of the energy.

Point of use energy measurement is often called the *site energy*; energy measurement that accounts for the extraction, generation, transmission and distribution of the energy is often called *source energy*. These are the terms that we will use throughout the report. Incorporation of extraction, generation, transmission and distribution losses into DOE and FTC policy, it is claimed, would give consumers a clearer picture of their energy use. Since the losses are markedly different for different energy types – natural gas and electricity for example – the effects of maintaining or changing policy could be significant for appliances in which there is a choice of energy sources. The problem of energy measurement is more complicated for homes since homes often use both electricity and another fuel.

This study addresses the question of whether the measurement of energy, for the purpose of setting or promulgating codes or standards, promotes the use of one fuel over another. If consumers only have the knowledge of the site energy consumption of an appliance or if standards and codes consider only site or source energy, does one fuel benefit over another? The results of RAND's analysis are straightforward though the DOE faces broader issues:

- Analysis does not support the claim that the site-based measurement used to promulgate minimum efficiency standards for water heaters favors electric units over natural gas units.
- There is no statistical difference in the market share of electricity between states with source-based residential energy codes or codes that are fuel-specific as a group and states with site-based residential energy codes as a group. The claim that the measurement of energy used to comply with residential energy codes adversely influences the broader market for natural gas and electricity is unsupported.
- There is preliminary evidence that states that use source-based energy codes or codes that are fuel-specific, as a group, are more efficient with respect to energy use per capita than other states.

DOE goals and policy

The DOE has a variety of goals with respect to energy use and the appropriate measure of energy consumption is closely related to each goal: energy costs and life-cycle costs quantify expenditure goals; pollution levels and distribution quantify environmental damage; fraction of energy derived from domestic sources is a measure of energy security; productivity of energy use indicates efficiency; and the market penetration of renewable resources marks their acceptance into the market. Since the DOE does not dictate the actions of consumers, builders, manufacturers and energy suppliers, its policies strive to target the motivating factors for each of these groups.

If the information that the DOE provides to consumers, builders, manufacturers and energy suppliers is to influence their energy-related decisions, it must be well considered in relation to the DOE's energy efficiency goals. The same comments apply to the process of setting codes and standards. Proponents of site energy accounting claim that since consumers only pay for the energy that enters their homes rather than the energy that is lost in generation, transmission and distribution, that site energy is the most appropriate measure of energy consumption at the consumer level; note, however, that retail electricity pricing often includes charges for maintenance of transmission and distribution resources in addition to charges for end-use electricity consumption. Its opponents argue that since site energy ignores up to 70 percent of the energy required to deliver electricity to a home, site energy causes consumers to make poor societal decisions with respect to energy use. Advocates of either measurement claim that since consumers receive incomplete information, their decisions with respect to energy use may favor one energy source over another (that energy source with the highest efficiency with respect to the measurement of choice.) A key result of this study is that neither the use of site or source energy use seems to have adversely affected the broader market for fuels.

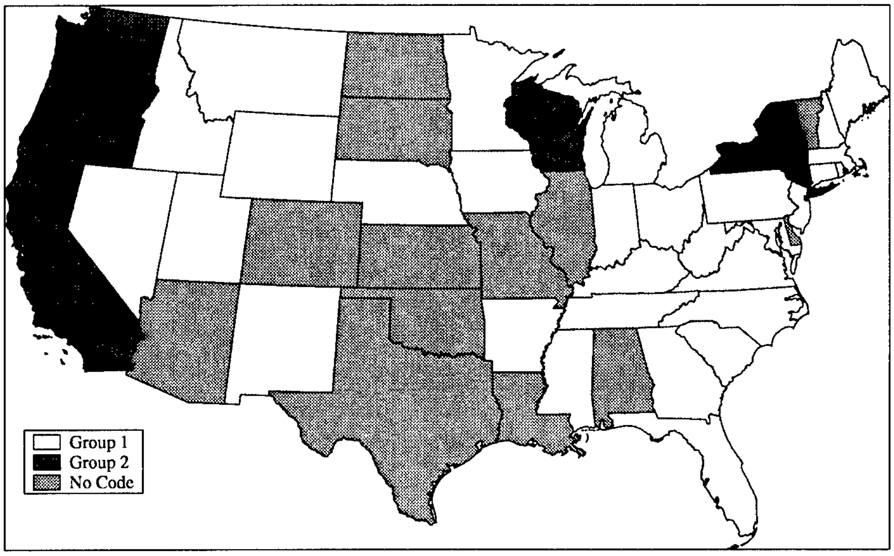

Figure 1. Geographical distribution of three groups of states.

We investigate if the choice of a particular measure of energy, either site or source energy, has had an impact on the fuel-use mixture in the residential market. On the national scale, we study the relationship between the EnergyGuide label for water heaters, which displays either the site-based efficiency rating or the site-based energy consumption, and historical shipments of natural gas and electric units. At the state level, through 1995, two thirds of states had implemented residential energy codes. A group of states had codes that were based on site energy and largely used revisions of the Model Energy Code (we label this group *group 1.*) California had a source-based code and several others had codes that required increased efficiency for homes heated with electricity (we label this group *group 2.*) A third group did not have energy codes or failed to enforce their codes (*no code*; see Figure 1.) We study the differences in the use of natural gas and electricity across these three groups of states. In addition, we study the impact of the residential energy codes on per capita residential energy consumption. Taken together, the set of results gives the DOE a picture of its options for meeting its energy efficiency goals in the residential sector.

Water heaters

The initial installation of a water heater is usually the responsibility of the builder, who may not consider the efficiency or cost of operation of the unit at the time of installation. Furthermore, since hot water is an essential service, when a water heater fails, speedy replacement of a broken unit may take precedence over considerations of energy efficiency. Despite these and other inefficiencies in the consumer market for water heaters, some claim that since the Federal energy efficiency standards and labels for water heaters are based upon site energy that a *de facto* preference for electric units exists; electric water heaters have typical energy factors (a rating of efficiency) of 0.88 while gas units have typical energy factors of 0.54.

Chapter II is an analysis of the national water heater market over the years of the DOE and FTC labeling program. From the quantitative analysis that examines the relationship between relative shipments of electric to gas water heaters, energy factor and operating cost, it does not appear that site-based information used in the EnergyGuide labeling program has affected the relative markets. If sensitivity in the market exists, it is to the relative cost of operation of natural gas and electric units and indicates that the standards to be promulgated by the DOE are unlikely to change the market share.

State residential energy codes – fuel shares and performance

Although the residential energy policy in each state is unique, one can place energy codes into three groups based on the existence and stringency level of the residential energy code as mentioned above. The list of states and groups appears in Chapter III. We study the shares of electricity and natural gas used in the residential sector in the three sets of states, and the effectiveness of the codes in terms of their impact on per capita energy consumption. Figure 2 is a plot of the average share of electricity in the groups of states from 1985 to 1995. Between the groups there has been little variation in the share of electricity in these years.

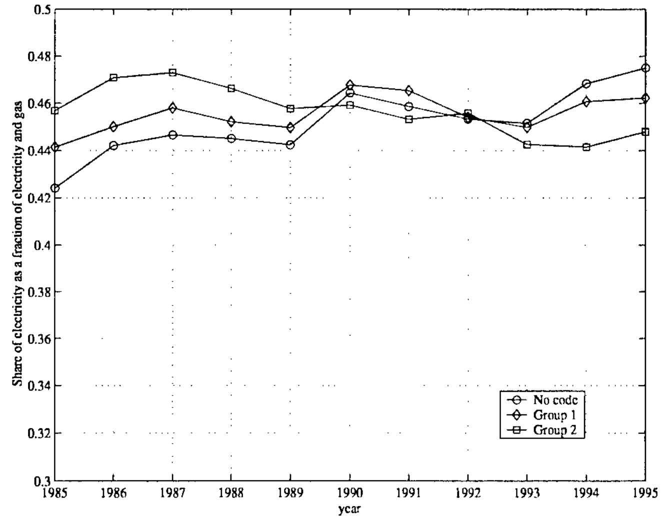

Figure 2. The average share of electricity in the sets of states from 1985 to 1995 as a fraction of electricity and natural gas.

The quantitative analysis of the fraction of natural gas and electricity in the three sets of states is the identification of the differences in fuel share since the implementation of the energy codes. The analysis shows that compared to the *no code* states, there is no statistically significant difference in the share of electricity and natural gas in the *group 1* and *group 2* states.

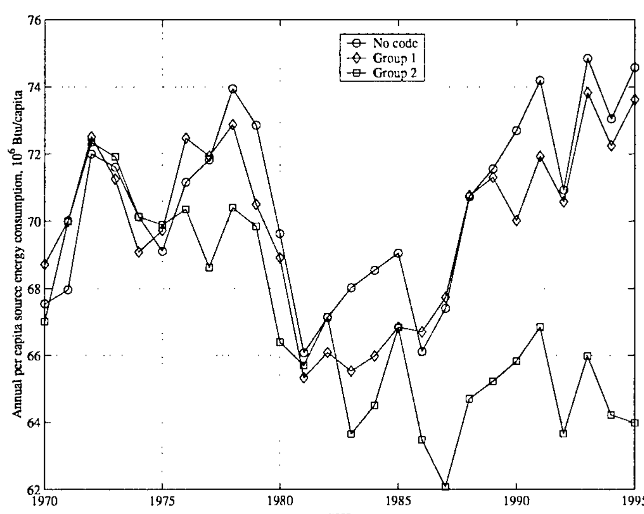

Figure 3. Average annual per capita energy consumption in the residential sector in the three sets of states. Energy includes all fuels and accounts for generation, transmission and distribution losses.

Recognizing that the purpose of a residential energy code is to reduce residential energy consumption in a cost-effective manner, not to equalize the market for electricity and natural gas, we also studied the performance of residential energy codes. Figure 3 shows the average per capita energy consumption in the residential sector in the states from 1970 to 1995. It appears that the *group 2* states were able to keep their per capita residential energy consumption from growing after 1985 whereas the *group 1* and *no code* states have seen dramatic increases in per capita energy consumption during these years. Our analysis verifies this observation when the benchmark of performance is the percent change in energy consumption from an average over the years 1970-1978. The reasons for these changes in energy consumption, however, are unexplored; the analysis is preliminary and a more detailed analysis would require an analysis of economic growth, climate differences, regulatory policies of states and other factors.

Summary of findings

1. With the available data, we have been unable to show that energy standards and labels for water heaters or residential energy codes based upon either site or source energy measurement have had significant impacts on fuel share.
2. DOE goals include reducing costs to consumers, increasing energy efficiency and reducing environmental effects. Our conclusions support the available literature, which suggests that a single measurement of energy consumption is not adequate to achieve all of these goals simultaneously for different regions of the country.
3. Our analysis shows that there is significant variation in the energy efficiency performance of states with different codes, and that it appears that states with codes that go beyond the Council of American Building Officials (CABO) Model Energy Code (MEC) may perform better. The results have a bearing on the current push to benchmark state residential energy codes against the MEC. The states listed in the *group 1* category largely base their energy code on the MEC. Facilitating the adoption of a code, even a stringent code, is not sufficient to guarantee reductions in residential energy use because total residential energy use depends on many factors beyond the control of the energy code. More analysis is needed to evaluate the reasons for these variations and help guide DOE policy and working relationships with the states.

I. The context of energy measurement

1. Scope

The Energy Policy Conservation Act (EPCA) of 1975 specified that the Federal Energy Administration, later the U.S. Department of Energy (DOE), develop test procedures, labeling policy and voluntary standards for various appliances. Since passage of EPCA, the natural gas and electricity industries have disagreed on the basis for the measurement of energy consumption. It is the belief of each group that quantifying gains in energy efficiency in terms of a particular measurement has adverse effects on the energy market, on consumer well-being, and on the environment, and, furthermore, is the basis for suboptimal DOE policy. In this report, we address the issue of energy measurement and how measures of energy consumption and efficiency are related to DOE policy. The DOE has a number of goals: among them are increasing energy efficiency, reducing costs to consumers and federal agencies, and minimizing effects on the environment. Each of these goals may be quantified in terms of a set of measurements that may affect the natural gas and electricity industries.

We organize our analysis and results to set the issue in a proper context, to address the concerns of the primary stakeholders, and to recommend a course of action that best promotes the multiple goals of the DOE. We begin by stating the several goals of the DOE and the measures that it may choose to quantify and mark its performance. The natural gas and electricity industries have reduced the debated energy measurements to the two that they feel best represent their interests: source energy and site energy. We perform a quantitative analysis of the national water heater market and of residential energy use at the state level to directly address the concerns of the natural gas and electricity industries because these are two markets in which the competition between electricity and gas is direct. We hope that the quantitative analysis will demonstrate to both natural gas and electricity stakeholders that energy measurements have not yielded anti-competitive effects to date. We close by revisiting the goals of the DOE in light of the analytical results and recommending actions that addresse the DOE's goals and current trends in the energy industry and in information technology.

2. DOE goals and objectives

The 1997 Strategic Plan of the DOE outlines the DOE's objectives. An objective of the DOE with respect to energy resources is to ensure the viability of a competitive electric generation industry that delivers "adequate and affordable supplies with reduced environmental impact (DOE 1997, 13)." A strategy associated with this objective is the development of "renewable energy technologies and supporting policies capable of doubling non-hydroelectric renewable energy generating capacity by 2010 (DOE 1997, 13)." Another objective with respect to energy resources is to "increase the efficiency and productivity of energy use, while limiting environmental impacts (DOE 1997, 15)." The Office of Energy Efficiency and Renewable Energy (DOE-EERE) implements many of the higher-level objectives of the DOE with the aggregate goal of developing "cost-effective energy efficiency and renewable energy technologies that protect the environment and support the nation's economic competitiveness (DOE-EERE 1999A)." DOE-EERE's Federal Energy Management Program (FEMP) oversees the energy use of the U.S. Government. A 3 June 1999 Executive Order entitled "Greening the Government" restated the goals of FEMP consistent with the Strategic Plan and the goals of the DOE-EERE (U.S. President 1999).

Each of the strategic or energy management goals has a corresponding figure of merit against which its performance is measured. The benchmarks for the monetary goals are reduced energy costs and reduced life-cycle costs of energy-consuming equipment relative to current and historic costs. Reduced total emissions of carbon dioxide, other gases and precursors to local pollution are measures of environmental progress. The percentage of the nation's electricity produced by renewable resources at some future time is an indicator of the success of renewable energy promotion programs. The energy use per square foot of a building is a measure of general energy efficiency.

If the DOE is to achieve these goals outside of federal energy management, it must influence the energy-use choices of consumers, builders, building managers, manufacturers and energy suppliers. Each group has a particular set of motivating factors. Consumers desire convenience, safety, reliability and service at minimal cost. Builders attempt to reduce production costs while satisfying the real and perceived needs of the consumers. Manufacturers create products for a market that includes consumers, contractors, retailers and builders. Energy suppliers need to deliver a product of uniform and consistent performance and value to their customers.

The DOE attempts to achieve some of the goals stated above through its programs targeted at energy producers and consumers. With the Federal Trade Commission (FTC) and the Environmental Protection Agency (EPA), the DOE labels appliances with energy efficiency information, including expected annual energy use and annual operating cost. Minimum efficiency standards for appliances eliminate the least efficient models from the market. State building energy codes prescribe insulation levels and the efficiency of major energy consuming systems and in some cases set performance standards. Government and utility sponsored rebate programs encourage consumers and builders to install efficient equipment. Government and industry sponsored research and development enables technological leaps in energy efficiency.

The policies, like the goals themselves, rely upon measurements of energy consumption for evaluation. In addition to characterizing the performance of energy management programs, the particular measurement of energy also describes a market in which there is a complex interaction among consumers, contractors, builders, manufacturers, retailers and energy suppliers. We investigate the historical role that energy measurement has played in the DOE minimum efficiency standards for residential appliances and in state energy codes, and how the choice of measurement has affected the marketplace for natural gas and electricity, two energy sources that are often in competition to provide services to consumers.

3. Energy measures and applications

On every new automobile sold in the U.S., there is a label from the Environmental Protection Agency (EPA) that gives an estimated miles per gallon for the automobile. The goal of the label is to give the consumer information regarding the fuel use of the vehicle so that it may be compared against the fuel use of other vehicles. Miles per gallon is a useful, easily recognizable and reasonable measure, though driving habits vary from person to person as do the definitions of "city" and "highway" traffic, and the achieved mileage is rarely what the EPA predicts. Because consumers pay for gasoline continually, they are very aware of the relationship between the fuel use of the car and the cost of operation. Miles per gallon is also only one measurement. Consumers may also be interested in fuel cost per mile, miles per dollar, or the total estimated cost of ownership for three or five years; the EPA may be interested in the weighted average fuel economy of all cars of a particular manufacturer.

Appliances and homes may be thought of as systems that consume energy and provide services in return. As with automobiles, there exist standard methods to measure energy consumption and energy efficiency. For water heaters, the figure of merit for energy consumed at the site is the energy factor (EF). A home is a system of energy consuming machines and people; the figures of merit for energy efficiency most often cited – if given at all – for homes are total energy use per year by fuel or total energy cost per year.

The EF for water heaters has a formal, engineering definition: the EF is the fraction of heat energy input as fuel or electricity that is converted to hot water. The energy required to raise the temperature of the water depends upon the amount of water used and its input and output temperatures, all of which are specified by a DOE test procedure. Like the EPA's miles per gallon rating, the EF and the consumption estimates derived from it may not reflect an individual's actual energy use. But unlike the MPG rating, which consumers can conceptualize, there seems to be a lack of understanding regarding interpretation of the esoteric EF. Likewise, to estimate energy use in the home, the average use of the collection of appliances in the home must be estimated against the home's insulation levels, environmental exposure and the expected weather. It is, at best, an imprecise process.

The EF is a measure of the efficiency of the water heater at the point of use. However, there are alternative ways to interpret efficiency. According to the National Appliance Energy Conservation Act (NAECA) and the accompanying U.S. Code, the term energy use refers to "the quantity of energy directly consumed by a consumer product at point of use (42 U.S. Code 6291)." The "point of use" language directs the DOE to develop and implement test procedures that depend upon the energy consumed at the site of operation of the appliance. The language makes for repeatable test procedures, but omits the amount of energy consumed to generate and deliver the usable energy to the appliance (from the energy source.) It is also possible to account for the energy required to generate, to transmit and to distribute the electricity to the consumer, and to incorporate this energy use into the efficiency rating. Were one concerned about reducing overall energy use, such energy consumption information might be useful to consider, especially if the consumer is comparing appliances that can use different fuel sources, such as water heaters. According to the *Annual Energy Review 1997*, 90 percent of the natural gas extracted was delivered to consumers – residential, commercial, industrial, transportation or electric utilities – while 29 percent of the energy consumed to generate electricity by electric utilities was sold as electricity (DOE-EIA 1998a). Most of the losses occur at electric generating stations, where most of the chemical energy in the fuel is converted to heat. Given the threefold difference in overall efficiency of natural gas versus electricity in energy production and delivery, there is a large disparity between the efficiency rating reported by test procedures, known as site measurements, and those that attempt to account for the extraction, processing, transportation, generation and transmission losses of the fuels, known as source measurements.

For homes, the problem is subtle. The average home uses electricity and natural gas or oil, though some are all electric, and the collection of appliances and end uses reflects in part the preferences of the builder, the homeowner (current and previous), the effect of national regulation on the appliances, and state or local regulation on home insulation and construction as well as the availability of natural gas. The tactic of labeling homes with respect to energy efficiency is new, but state energy codes are not. California bases its residential energy code on the total energy consumed by the home when compared to a model home. Other states, such as New York and Wisconsin, have different requirements for homes that are heated with electricity versus fossil fuels or wood. Many states have prescriptive codes, which dictate minimum levels of insulation and the efficiency of the appliances. And finally there are several states with no residential energy codes.

As in the case of automobiles, the EF of an appliance or the total energy used by a home – accounted at the point of use or the energy used in generation, transmission and distribution – is only a single measurement of the energy consumption of an appliance or building. There are additional measurements that could be useful to consumers, such as estimates of the environmental damage associated with the use of an appliance or home, the annual operating cost and the life-cycle cost.

4. Site vs. source

Though there are many ways to calculate energy consumption for the use of either consumers or policymakers, two have maintained the interest of energy industry stakeholders for the past 25 years: site and source. Site energy is the energy consumed at a location to perform a particular function, such as water heating or lighting. Source energy, as defined by the California residential energy code – and adopted for our analysis – is "the energy that is used at a site and consumed in producing and in delivering energy to a site, including, but not limited to, power generation, transmission, and distribution losses, and that is used to perform a specific function, such as space conditioning, lighting or water heating (CEC 1995b)." Source energy refers to the energy consumed in generation, transmission and distribution for electricity and to the energy consumed in extracting, transporting and removing the impurities from natural gas.[1]

In legislation and DOE policy the concept of site energy, which is relatively easily measured, has been dominant. The first mention of site energy occurred in the Energy Policy and Conservation Act (EPCA) in 1975 and it is the "point of use" language of the U.S. Code. In each subsequent piece of legislation, the "point of use" language has been reaffirmed. In June 1998, the Senate committee on appropriations issued a report in which it noted the current policy and directed a change.

> The Committee understands that the appliance efficiency standards promulgated by the codes and standards programs at the Department of Energy presently reflect only the energy consumed at the point-of-use. The Department also funds activities and makes purchases based on point-of-use energy consumption. This method ignores the total energy consumed over the full fuel cycle and costs, and may result in misleading conclusions about the success of certain departmental programs. With regard to energy measurement or efficiency standards, Federal facilities and buildings, energy purchases, participation in or funding of standard setting organizations, the Committee expects the Department to increase greatly its efforts to consider the total energy consumed over the fuel cycle as well as emissions and energy costs (U.S. Senate 1998).

[1] A weakness of source energy analysis, its opponents note, is that there is no common definition of it. See page 8 for alternative definitions of source energy.

The House echoed the sentiments of the Senate: "In measuring energy for efficiency standards, for Federal facilities and buildings and for dealings with standard setting organizations, the Department [of Energy] should consider the total energy consumed over the full fuel cycle, emissions and energy costs. This applies to all programs funded under the energy conservation appropriation (U.S. House 1998)." The directive from the committees is straightforward: the Department of Energy (DOE) should consider the total amount of fuel used to deliver energy to an appliance – be it a refrigerator, water heater or clothes dryer – or to a building, in addition to the energy consumed at the point of use, when making policy.

There remained Senators who objected to any change in policy. Senator Frank H. Murkowski inserted into the Congressional Record a letter on behalf of Senator Tom Harkin, Senator Chuck Grassley, Senator Craig Thomas, Senator Michael Enzi, Senator Larry Craig, Senator John Glenn and Senator Jan Kyl opposing the report's language on historical and scientific grounds. "Congress and the President wisely rejected such an approach [gross energy use] in 1975 and in succeeding debates in recognition that determining the energy use of an appliance at its point-of-use is a measurement, while attempting to factor in various exogenous factors is an attempt to estimate that which cannot be measured, projected, quantified or extrapolated with any real accuracy. It is a case of comparing hard, objective measurements with soft, subjective estimates (Murkowski et al. 1998)." Though this action by Congress encourages the DOE to address source energy, the Energy Policy and Conservation Act (EPCA) of 1975 still directs the DOE to measure energy consumption at the point-of-use (42 U.S. Code 6291).

The Clinton Administration has vocalized its support for source energy measurement and analysis. The language has appeared in an Executive Order with the title "Greening the Government through Efficient Energy Management." It directs: "The Federal government shall strive to reduce total energy use as measured at the source and associated carbon emissions. To that end, agencies shall undertake cost effective projects where source energy decreases, even if site energy use increases. In such cases, agencies will receive additional credit, through guidelines developed by the Department of Energy, toward energy reduction goals (U.S. President 1999)." Vice President Al Gore and Energy Secretary Bill Richardson have commented recently on the issue. "I don't have to tell you that the 'site versus source' issue is a long-standing one, and that the statutes and Executive Orders that have governed the accounting of efficiency benefits, using both of these methods, have not been consistent," said Gore. "The Administration wants the best possible information to reach those making decisions about efficiency in buildings, equipment, appliances and the like (Gore 1999)." The Secretary displayed a broad perspective on the issue: "There are appropriate uses for both site-based and total energy accounting (Richardson 1999)." The DOE does consider source energy consumption as part of procedure for setting appliance efficiency standards (see Section I.5 of this report.)

The language used to characterize either site or source energy measurement is so strong because both the natural gas and electricity industries believe it is the key to increased market share. The natural gas industry believes that policies based on site energy give an unfair advantage to electricity; the electricity industry believes that a change to source energy would unfairly benefit the natural gas industry. Citing the Edison Electric Institute's (EEI) *Washington Letter* of 23 October 1998, Mark Krebs of LaClede Gas Company reinterprets the EEI language: "...electric utilities are receiving 'billions of dollars' of government subsidies by maintaining site-based energy efficiency standards (Krebs 1999)." Those in favor of site energy simply reverse the allegation: "One of these special interests [the AGA] has gone on record in their own publications as promoting the use of source energy analysis in order to gain competitive advantage (Bernadowski 1999)."

One goal of this report is to determine if any competitive advantage exists with respect to policies based on site or source energy. While markets and sales are primary motivating factors in the site vs. source debate, there are subtleties and legitimate arguments supporting either side. We summarize the arguments of the primary stakeholders in six categories: definitions, estimation, environment, energy industry deregulation, fuel preference, and relevance with respect to DOE policy and enabling legislation. Later, we explicitly address the issue of fuel preference in the quantitative analysis of the national water heater market and the analysis of residential energy codes.

The definition of source energy from the California residential energy code is one of few published definitions. It may be inferred from the natural gas industry literature that source energy is an energy accounting method that accounts for the "energy consumed in the production, generation and transmission" of either natural gas or electricity (Fritts 1999). However, critics of source energy are quick to point out details that complicate the issue. First, in any particular region, the mixture of energy sources that contribute to the delivered electricity is unique and varies over time. Second, for renewable resources, there does not exist an accepted conversion factor that facilitates comparison among hydroelectric, biomass, wind or solar power, or between renewable technologies and fossil fuel systems since renewable systems do possess embodied energy (Heiss 1999; Bernadowski 1999). Critics of source energy finally note that it is protean and may include the embodied energy of the steel and concrete that comprises a dam or power station. "Where do you draw the box?" asks one critic rhetorically (Brundage 1999).

California calculates source energy for electricity through a conversion factor of 10,239 Btu/kWh[2]. This is a statewide average of the electricity mix over a year; the California Energy Commission (CEC) considers changes to the various conversion factors with each code revision. But even in California, the conversion factor represents only a statewide average. Source energy analysis relies on estimates "of factors that are virtually impossible to measure, predict, quantify or extrapolate (CPAES 1998)." Virginia Power notes: "Typical source energy analyses do not recognize time-of-use, regional, local, application or availability specific impacts on data or inputs (Bernadowski 1999)." Source energy opponents uniformly echo the sentiments of Virginia Power. Electricity deregulation is likely to alter the source mix attributable to each customer. Source energy advocates admit the significant regional variation and the complicating penetration of renewable resources; however, in electric utilities 57 percent of electrical generation is powered by coal, 9 percent by natural gas, 20 percent by nuclear, 11 percent by hydroelectric and 3 percent by additional sources (DOE-EIA 1998a). The "additional sources" includes renewable resources. By some estimates, this mixture is not expected to change appreciably in any given year (DOE-EIA 1998d). However, if DOE programs promoting research, development and implementation of

[2] A direct conversion between the two units is 3412 kWh per Btu. The conversion and delivery efficiency of the electricity in California, according to the CEC, is 33 percent, 3 percent greater than the national average.

renewable energy and clean fossil fuel technologies are successful, then the overall mix of electricity generation could be cleaner in the future; according to these estimates, renewable energy has the potential to generate 350 billion-kilowatt hours displacing 45.3 million metric tons of carbon per year by 2020 (Arthur D. Little 1999a; NREL 1999).[3] Source energy proponents note that although it is difficult to structure source energy estimates to account for renewable resources, site measures of energy ignore the differences in generation altogether. Advances in information technology and real-time access to information regarding generating resources have reduced the impediments to maintaining accurate source energy estimates.

Both sides of the site vs. source debate lay claim to the environmentally friendly position. Source energy, its detractors complain, does not consider the "scarcity of resources, local environmental issues or global environmental issues…it does not consider the environmental consequences of the energy use choice (Brundage 1999)." California and the DOE use a fixed conversion rate to calculate source energy consumption. Site energy proponents suggest that since the fixed conversion rate is incapable of accommodating local variations in energy production and delivery, it is also unable to quantify the benefits of local renewable generation. Such comments by site energy proponents irk source energy advocates, who count among themselves the Alliance to Save Energy – an energy-efficiency and environmental advocacy group. Quite simply, source energy proponents argue that site energy ignores differences in the energy sources used to provide electricity to a home and ignores the environmental consequences of electricity. While source energy does not yield measures of pollutants, it is much more closely related to them than its counterpart (Krebs 1999).

Both sides claim that they provide consumers in deregulated energy markets the most comprehensive information regarding energy use. "[Source energy] is meaningless and confusing to consumers, who need information on the amount of energy they will be expected to buy and the cost of that energy. This need will become even more critical for

[3] Given current estimates for growth in electricity demand, an additional 350 billion-kilowatt hours of renewable generating capacity would result in a market share of 15 percent for renewables, including hydroelectric generating units. Likewise, the 45.3 million tons of saved carbon is approximately 6 percent of the projected carbon emissions due to electricity generation and approximately 2 percent of total carbon emissions, in the absence of new measures to control emissions (DOE-EIA 1998d).

consumers as they gain the ability to shop for their energy," notes Virginia Power (Bernadowski 1999). In its most simple terms, "consumers pay only for energy they consume at the site, any attempt to interject source energy into their decision-making process will be confusing at best – misleading at worst (EEI 1998)." Consumers will demand more accuracy in the information they receive. "In the restructured future…the heating values (Btu per kWh, Btu per therm, or Btu per gallon) may change on a daily or hourly basis (Kuhn 1998)." The logical consequence of this position is that the volatility in the energy marketplace will make source energy obsolete. Source energy may lead to only perceived energy improvements. An energy manager may change to more efficient suppliers and claim a savings in energy without performing any action at the building site (EEI 1998).

Source energy advocates note that "deregulation and restructuring places increased emphasis on comparisons across fuel types that are equitable and consistent with economics (Pennington 1999)." Economic factors include the costs (environmental and financial) to produce and deliver that energy; in California, for example, electric utilities "want greater differentiation of the 'value' of energy by time-of-use and season that give signals that are consistent with the economics of delivering energy services – site energy is an obsolete concept and completely inadequate for meeting this need (Pennington 1999)." As discussed later, neither measure seems to provide information that influences consumer decisions.

Both sides reserve their most intense and contentious language for energy efficiency codes and standards. Fortunately, the positions are the simplest to state. "The use of source energy analysis in these types of applications [energy efficiency standards] always produces anti-competitive and discriminatory results. An example of this result is the current situation in California where it is extremely difficult for electricity to compete with fossil fuels for certain uses such as space heating and water heating due to source-based state energy efficiency regulations (Bernadowski 1999)." Source energy advocates state that the use of site energy in standards and rating results in a *de facto* discrimination against fuels other than electricity (Pennington 1999). By discrimination, the stakeholders mean that the site-based or source-based policies involuntarily force consumers into purchases of appliances that use the opposing fuel – electricity for source energy and natural gas for site energy. It is this topic that we address in the following chapters; neither point of view is supported.

The final battleground that we discuss is legal. As before, it is straightforward to state the opposing viewpoints. The EPCA instructs the DOE to develop efficiency standards based on the energy measured at the point of use for a set of appliances. It also directs the DOE to label the appliances with the energy efficiency information (42 U.S. Code 6294). While the law directs the DOE to consider net energy use when evaluating consumer appliances and setting standards, it also allows the DOE to provide the consumer with "additional information [that] would assist [him] in making purchasing decisions (42 U.S. Code 6294(c)(5))." Source energy advocates claim that the omission of the gross energy consumption information results in inconsistent ratings across consumer goods for which there is a fuel choice – water heaters or homes, for example (AGA 1999). Representatives of the natural gas industry state that because of the relative inefficiency of delivering energy in the form of electricity to consumers, the DOE policies result in a *de facto* preference for electric power at a hefty environmental cost (Kalisch 1998). Since the publication of the supportive language in the Senate and House reports, both the AGA and the EEI have been thorough with their praise or criticism (Krebs 1999; Wethje 1999; CPAES 1998).

5. Implementation of current policy

This section is a summary of DOE policy with respect to appliance standards, home energy rating systems (HERS), and the site vs. source issue. The DOE itself describes the legislative history. We quote from it at length:

> The Department of Energy's appliance standards program is conducted pursuant to Title III, Part B of the Energy Policy and Conservation Act (EPCA). 42 U.S.C. 6291-6309. In 1987, EPCA was amended to establish by law national efficiency standards for certain appliances and a schedule for DOE to conduct rulemakings to periodically review and update these standards. National Appliance Energy Conservation Act, Pub. L. 100-12 (1987). The products covered by these standards included refrigerators...In conducting the rulemakings to update the standards, the Secretary of Energy is to set standards at levels that achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified...

EPCA also provides for DOE to establish test procedures to be used in evaluating compliance with efficiency standards. These test procedures are revised periodically to reflect new product designs or technologies.

As prescribed by EPCA, energy efficiency standards are established by a three-phase public process: Advance Notice of Proposed Rulemaking (ANOPR); Notice of Proposed Rulemaking (NOPR); and Final Rule. The process to develop test procedures is similar, except that an Advance Notice is not required (DOE-EERE 1996).

The origin of energy policy legislation in the U.S. is the energy crisis of the early 1970s. The EPCA passed in 1975. It successors are the National Energy Conservation Policy Act (NECPA) (1978), the National Appliance Energy Conservation Act (NAECA) (1987) and the Energy Policy Act (EPACT) of 1992. The EPACT outlines the environmental motivation of current energy policy; it contains sections on renewable resources, alternatively-fueled vehicles and the like. For example, the EPACT's "Least Cost Energy Strategy" outlines several measures that "shall be designed to achieve to the maximum extent practicable and at the least cost to the Nation:

The stabilization and eventual reduction in the generation of greenhouse gases;

An increase in the efficiency of the Nation's total energy use by 30 percent over 1988 levels by the year 2010;

An increase in the percentage of energy derived from renewable resources by 75 percent over 1988 levels by the year 2005...(EPACT, sec. 1502)."

Although standards are promulgated through a site energy measurement of energy use, the DOE bases the standard on several factors. Indeed, the test procedures measure the energy consumed by an appliance at the site but it is only one aspect of the standard setting process. Each standard must satisfy the "technologically feasible and economically justified" provisions of the legislation. Technological feasibility is determined through a series of notices of rulemakings and comments in which manufacturers and retailers comment on various design options for the product. To satisfy the "economically justified" provision of the legislation, the DOE must "determine that the benefits of the standard exceed its burdens, based, to the greatest extent practicable, on a weighing of seven factors (DOE-EERE 1994)." These seven factors are the economic impact on manufacturers and consumers, the life-cycle cost savings of the product, the total energy savings due to the standard, a possible reduction of the performance of the product due to the standard, the possible lessening of competition in the industry, "the need for national energy conservation", and any other factor that the Secretary of Energy determines is relevant (DOE-EERE 1994). Standards are specified in terms of site energy, after weighing a set of factors that includes the source energy consumption of the appliance. The stakeholders – manufacturers, retailers, contractors, builders and consumers – comment on all aspects of the standard setting process, including the unit lifetime, the manufacturing and retail costs, the fuel price scenarios, the range of discount rates, and the test procedures.

The EPCA also instructs the DOE, along with the FTC, to label appliances with information on their energy consumption; the program manifests itself as the conspicuous yellow EnergyGuide stickers that adorn appliances. According to the statute, labels may be developed for any product covered by a standard if the FTC or the DOE "has made a determination with respect to such type [of product] that labeling...will assist purchasers in making purchasing decisions (EPCA Sec. 324)." For water heaters, the format of the label changed in the 1980s, but the information contained on the label remained the same. The EnergyGuide label for water heaters contains information on the annual operating cost and the annual energy consumption (at the point-of-use). There is a hierarchy to the information: the energy consumption information (on the latest version of the label) is prominent and the operating cost information is subordinate. The label provides a range of values (in terms of operating cost in the previous format and energy consumption in the current format) for similar models so that the consumer may compare units against one another. The comparison is for models of the same fuel and similar size and performance.

The available studies of the influence of the EnergyGuide program, and the related EPA Energy Star® program, on consumer behavior is inconclusive. Du Pont and Lord report that "a large percentage of consumers either ignore or misinterpret the labels (du Pont and Lord 1996)." The EPA and DOE Energy Star® logo adorns appliances such as clothes washers, refrigerators, dishwashers, and room air conditioners. According to the EPA, "an appliance receives the Energy Star® rating if it is significantly more energy efficient than the minimum government standards, as determined by standard testing procedures (EPA 1999)." The Energy Star® program encourages consumers to purchase appliances that exceed the DOE minimum efficiency standard. Analyses of the Energy

Star® program indicate that while consumers do use this additional piece of information, it does not necessarily give consumers the essential information regarding energy efficiency to influence purchasing decisions.

> Asked if they had seen the Energy Star® logo before, 42 percent of participants registered awareness of it. A few more, 68 percent, had seen the EnergyGuide label and knew what information was on it. Although almost two-thirds claimed the label was considered in their purchasing decision, it was considered only moderately to somewhat useful.
>
> When presented with choices of ways in which they would like to see energy efficiency information stated, respondents chose "Dollars Saved," closely followed by "Dollars of Operating Costs." (Brown & Whiting 1997).

The labeling programs have not made the transition to the internet: though Sears sells appliances via the world wide web, as of this report its "side-by-side" comparisons of appliances do not include energy efficiency information (Sears 1999).

Residential energy codes are state-level mechanisms for regulating the energy efficiency of homes. The EPACT directs each state to revise its energy codes (both residential and commercial) such that the building code provisions "meet or exceed CABO Model Energy Code, 1992 (EPACT 1992, 304(a)(1))." While states are free to develop and implement building energy codes, the codes are benchmarked against a national standard. The EPACT also directs the DOE to develop a home energy rating system (HERS): "voluntary guidelines that may be used by state and local governments, utilities, builders, real estate agents, lenders, agencies in mortgage markets, and others, to enable and encourage the assignment of energy efficiency ratings to residential buildings (DOE-EERE 1995)." Like the EnergyGuide label, a HERS is supposed to make a connection with the consumer regarding the energy consumption of the purchase and HERS programs already exist in many states. A HERS calculates the energy performance of a home with respect to a standard. According to the DOE: "An accurate home energy rating system will give the lending industry the confidence it needs to underwrite energy efficiency mortgages, offer financing mechanisms, and provide the real estate and appraisal industries with a basis for valuing energy efficiency in the home sale and resale markets (DOE-EERE 1995)." The proposed federal HERS program was site-based and references the MEC as its standard. Regardless of site or source energy, the goal of the HERS rating is to establish a measure for energy efficient mortgages and induce competition for energy efficiency, it is a market-based approach to energy efficiency (Verdict et al. 1998).

The site vs. source issue superceded the market-based goals of the national HERS program. Despite objections to the site-based methodology of the ratings, the AGA and other source energy proponents approved the initial national HERS technical committee guidelines. In response to the notice of public rulemaking, several stakeholders commented on the inadequacy of the site-based ratings. The California Energy Commission (CEC) provided the most succinct explanation: "Under the proposed regulations two homes with identical energy features, except that one has an electric resistance water heater and the other a gas water heater, will receive exactly the same rating. However, the energy bills for these two homes could be widely different with identical patterns of energy consuming behavior. This situation discriminates against natural gas, and creates conflicting signals to consumers and lenders that will reduce the credibility of HERS and reduce investment in energy efficiency (Deter 1995)." In late 1995, the Florida Solar Energy Center, in a test calculation, showed that two similar homes, one with electric appliances and one with natural gas, would receive different ratings: the electric home would be rated higher. During the spring of 1996, a "fuel adjustment factor" became the source of debate (Fairey 1996). When the "adjustment factor" failed to satisfy the AGA that the national HERS had addressed the site vs. source issue, the AGA withdrew from the negotiations. The site vs. source issue killed the national HERS program.

It is not clear that a national HERS program, being voluntary, would actually promote residential energy efficiency. The goal was to institute market-based incentives for energy efficiency as regulatory programs, such as residential energy codes, fell from favor. Jeff Ross Stein and his colleagues at the Lawrence Berkeley National Laboratory have questioned the accuracy of state HERS programs. Stein compared the energy usage of rated homes as predicted by the HERS rating with the actual energy usage in California, Colorado, Kansas, and Ohio. "None of the HERS we examined showed any clear relationship between rating score and total energy use or energy cost (Stein 1997)." The precision of the rating, he concludes, is essential to the widespread acceptance of such a system. It is questionable that a national program could have achieved higher precision.

6. Two case studies: the national market for electric and natural gas water heaters and state residential energy standards

The site vs. source battle has continued over programs whose effects on the market are unclear: the EnergyGuide label and HERS programs. Both are the consumer-based components of larger programs in which the measurement of energy is contentious: minimum efficiency standards for appliances and residential energy codes. Since appliance standards and building codes actively regulate the market, we investigate if these programs have shifted the market for natural gas and electricity due to the use of site or source energy measurement. Since both sides of the site vs. source debate contend that policies have adversely influenced consumer choices, we focus upon the residential market.

The water heater is an appliance that delivers an essential service to the home and bears a significant load of the household energy use (DOE-EIA 1995). An installed water heater guarantees consistent energy sales for years or decades. If DOE policy were to shift the market toward either electricity or natural gas, there would be a corresponding gain and loss of billions of dollars of energy sales. We investigate the effect of the site-based rating on the national market for water heaters.

Many states responded to the energy crisis through the implementation of building efficiency programs, including residential energy codes. Though the codes vary considerably among the states, they may be categorized as based upon site or source energy consumption. Accordingly, we investigate the effect of the code on the sales of electricity and natural gas within the states. We also assess the performance of the states in reducing per capita energy consumption.

II. The national market for natural gas and electric water heaters

1. Why water heaters?

There is a junior high school science experiment in which one measures the input of energy into water to determine the specific heat. The answer, quite simply, is one calorie per gram: one calorie is the energy required to raise the temperature of one gram of water by one degree Celsius. Given that a sugar cube contains an embodied energy of 15 kilocalories – enough energy to raise the temperature of a liter of water 15 degrees Celsius – the specific heat of water seems small indeed.

To illustrate the energy use and costs of water heating in a typical home, consider another experiment. For sake of convenience, use the parameters given by the DOE for their test procedure for storage water heaters (DOE-EERE 1998b).[4] The daily water use is 243 liters, the inlet water temperature is 14.4 degrees Celsius and the hot water temperature is 57.2 degrees Celsius. The energy required to raise the temperature of 243 liters of water from 14.4 degrees Celsius to 57.2 degrees Celsius is 10.4 million calories - equivalent to 41,200 Btu or 12.1 kWh. However, in our simplified analysis, we have not accounted for the efficiency of the water heater. The EF takes into account both the efficiency of the heating process and the heat loss of the stored hot water over the course of a day. A typical existing natural gas water heater has an EF of 0.54 and a typical existing electric water heater has an EF of 0.88. Adjusting the daily energy figure in consideration of the efficiency of the unit and converting to more familiar units, the natural gas water heater uses 0.76 therms of natural gas per day and the electric water heater uses 13.8 kWh of electricity per day. The costs per day, at the 1998 average prices (DOE-EIA 1999c), are US$0.51 and $1.16 for natural gas and electricity respectively. The monthly costs are $15.40 and $34.80; the annual costs are $187 and $423

[4] The DOE explicitly states that the test procedure is to "measure energy efficiency, energy use, or estimated annual operating cost of a covered product during a representative average use cycle or period of use (DOE-EERE 1998b.)" If the use cycle is truly "representative" is open to debate.

respectively. In 1993, water heating accounted for 18 percent of the energy consumption and 14 percent of the energy costs in the residential sector nationwide (DOE-EIA 1995).

Americans consume a significant amount of energy and spend a lot of money for the basic task of heating water. It is straightforward to categorize good water heater performance: the water heater should produce hot water, replenish its supply quickly, and last for a decade or more with little maintenance. And unlike furnaces, water heaters draw a power load all year. An added advantage of electric water heaters for electric utilities is that the penalty associated with brief power outages is low. Consequently, electric and gas utilities want as many water heaters corresponding to their fuel installed in a region as possible. The EEI and the AGA claim that the site vs. source issue is critical to the installation of electric or natural gas water heaters.

The water heater is an appliance that few consumers choose themselves and for which the operating costs are significant yet often ignored; it is a consumer analyst's nightmare. Within the context of the site vs. source debate, the water heater has a number of unique and subtle properties. On a national average, electric and natural gas water heaters have significant differences in their source energy use and emissions, operating costs and first cost, figures from our simple calculations that appear in Table 1. The DOE is also in the final stages of a rulemaking for an update to the minimum efficiency standards for water heaters. Together, these factors are the motivation for a quantitative analysis of the water heater market and an assessment of the possible effects of the site-based efficiency rating and labels on the national market for water heaters.

Water heater type	Electric resistance	Natural gas
DOE efficiency rating, EF	0.88	0.54
Source energy consumption (10^6 Btu/year)	56.6	31.3
CO_2 emissions (kg/year)	3480	1470
SO_2 emissions (kg/year)	18	0
NOx emissions (kg/year)	11	N/A
Annual operating cost ($/year)	423	187
First cost including installation ($)	328	334

Table 1. Summary of energy and cost characteristics for electric resistance and natural gas water heaters. (DOE-EIA 1999c; LBNL 1999).

2. Qualitative and quantitative analysis of the national market for residential water heaters

The AGA claims that the labels for water heaters are misleading. The EnergyGuide labels for water heaters state the annual energy use predicted by the DOE tests, a comparison of the fuel use with similar models that meet the standard, and a statement of the annual energy cost based upon DOE national averages. The EF, when it does appear, is on a separate sticker with no further explanation. However, "the average consumer does not understand that an electric water heater with an EF of 0.92 requires twice as much energy to be produced as a gas water heater with an EF of 0.56. These labels are misleading to consumers who care about the amount of energy they consume, the cost to operate the appliance, and the emissions associated with those appliances (Kalisch 1998)." Although the EF is not directly reflected on the EnergyGuide label, the result of the policies is consumer confusion and a distortion of the marketplace in favor of electric storage water heaters.

Most consumers do not view the EnergyGuide label before purchase. The Office of Technology Assessment concluded in 1992 that since "this equipment supplies essential services (heat, hot water), there is usually a high cost to delaying the purchase; contractors will often install the unit that is easiest to obtain, rather than the most efficient. Consumers may be unaware that they can choose a more efficient unit, or they may want the contractor to put in the cheapest unit that will deliver the needed service (U.S. Congress 1992, 80)." For the consumer, the services that water heaters provide probably outweigh consideration of energy efficiency.

The site vs. source battle is fought at the lobbyist and energy supplier level, not the manufacturing level. Over its useful life the energy costs of a water heater are an order of magnitude more than the first cost of the unit. Manufacturers of storage water heaters maintain almost identical market shares in both electric and natural gas units (DOE-OCS 1998d).

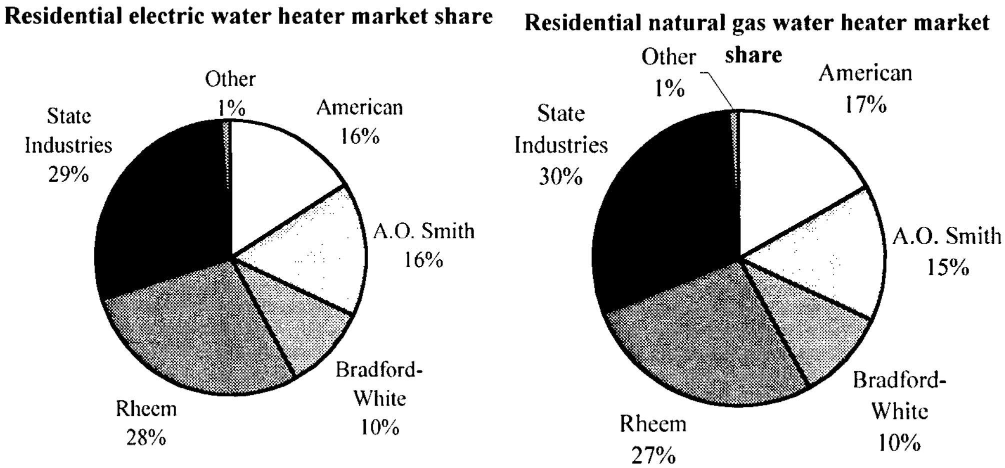

Figure 4. Manufacturer market share of electric and natural gas water heaters in 1995 (U.S. DOE, 9 Nov. 1998).

Though water heaters use up to 20 percent of the energy in a household, there are surprisingly little data and few analyses of the water heater market. James McMahon of the Lawrence Berkeley National Laboratory commented to an audience of water heater manufacturers and gas and electricity industry representatives about the dearth of detailed data: "There is not, at least to my knowledge, a publicly available dataset of water heater prices...The fuel shares, we expect, will depend upon fuel availability, operating expenses, installed costs, and utility programs. If anyone has a forecast of all those things regionally, I'd be happy to have it. No, huh? Okay (DOE-OCS1998f, 164-167)." The state of affairs presents a problem since we would like to calculate the dependence of the fuel shares on a quantitative variable: the standard and the EnergyGuide label as represented by the site-based EF.

The few analyses of the EnergyGuide labels are inconclusive regarding the ability of the labels to influence consumers. The OTA concluded in 1992 that "after 12 years, U.S. experience with appliance labeling is fairly extensive, but the value and impact of that experience remain poorly understood, primarily from a lack of regular program evaluation (U.S. Congress 1992, 115)." The 1986 FTC review of the first seven years of the labeling program was inconclusive.[5] As early as 1981, researchers concluded that the EnergyGuide labels were ineffective without "sales push" of the efficient appliances

[5] R.F. Dyer, "A Longitudinal Analysis of the Impact of the Appliance Energy Labeling Program – Final Report," November 1986, prepared for the Federal Trade Commission, Office of Impact Evaluation.

(Redinger and Staelin 1981). More recently, du Pont and Lord interviewed policymakers and consumers to quantify each group's conception of energy efficiency. The sample size was small and the study qualitative but their conclusions were meaningful: "We also found a substantial amount of confusion and misconception about the meaning and reliability of the EnergyGuide labels. This supports previous research, which has indicated that a large percentage of consumers either ignore or misinterpret the labels (du Pont and Lord 1996)." The OTA did note that life-cycle costs would "increase the value of the current appliance labels (U.S. Congress 1992, 115)." "Life-cycle cost information would impart more complete information about comparative appliance costs, but making allowances for retail price shifts and determining appropriate discount rates could complicate such an effort (U.S. Congress 1992, 116)."

While energy efficiency is one factor that a consumer may use to make a decision, other factors such as the unit cost, warranty, brand recognition, maintenance contracts, performance and cosmetic features also influence that decision. The studies on the U.S. labeling program for appliances concern refrigerators and clothes washers. These are appliances that a consumer is likely to compare across various models (DOE-EERE 1999b). As we have previously mentioned, a water heater delivers an essential service for which the cost of delaying installation is high. Also, given that consumers often do not choose the fuel or the model of water heater, we conclude that the EnergyGuide labeling program for water heaters is probably less effective than it is for other appliances.

The ineffectiveness of the labels on water heaters, the peculiarity of water heaters, and the DOE methodology for setting the standard combine to sharply reduce the relevance of the site vs. source measurement issue as a factor in determining the shares of gas and electric water heaters at the national level. Most people do not choose the original fuel for their water heater and do not plan its replacement. Furthermore, the DOE does not set the standard for water heaters based solely upon the EF of the units for different fuels but rather on cost and engineering analyses that review and preclude design options that dramatically shift the prices of the units. The effect of the EnergyGuide labels for water heaters, or the standard to be promulgated by the DOE, as they relate to the site vs. source issue at most can have a marginal effect on the market share of gas and electric water heaters.

Appendix A.1 contains a quantitative analysis of the national residential market for water heaters. We identify a simple model that relates the relative shipments of electric to gas water heaters to the relative EF and the relative operating cost of the units. If there exists a market distortion, we would expect to find a strong correlation between the relative shipments and the relative energy factor. We do not. The statistically significant relationship is between the relative shipments and the relative operating cost. The small size of the available data and other limitations constrain the conclusions.

Claims that the site-based EF used by the FTC in the EnergyGuide labeling program has had an effect on the market for gas and electric water heaters cannot be supported empirically at this time. Since the standard to be promulgated by the DOE uses site energy efficiency calculations as well as manufacturer and life-cycle cost analysis in addition to other factors, it is unlikely to change the market share of electric and gas water heaters. Previous studies of the EnergyGuide labeling program coupled with the peculiarity of water heaters as a consumer good and the methodology of the DOE standards-setting process form a convincing argument that any effect of the site-based measurement of energy consumption on the fuel share is marginal.[6]

3. Implications of the analysis on the DOE rulemaking

The DOE sets the standard for gas and electric water heaters based in part upon the least life-cycle cost of the proposed design options. The design options that the DOE considers are those that are technologically feasible and economically justified. The technological feasibility considers the manufacturability, the installation and service infrastructure, the product utility and the health and safety effects of the design options (Logee 1998). The DOE considered eight design options for the engineering analysis: heat traps, plastic tanks, increased insulation, improved flue baffles and forced draft, increased heat exchanger surface area, fuel damper, side-arm heater, tank bottom insulation for electric units and electronic ignition for gas units (DOE-EERE 1998a). The engineering analysis determines the efficiency improvement and costs associated with

[6] A straightforward quantitative analysis of the data further supports the conclusion; see Appendix A.1.

each set of design options (DOE-OCS 1998a). The life-cycle analysis calculates a distribution of life-cycle costs for each of the proposed design options and reports results in terms of the percent of the population benefiting from a standard set at a particular design and the average life-cycle cost benefit with respect to a baseline model. The life-cycle cost analysis uses distributions of the uncertain input parameters: the discount rate, the life of the water heater, the costs of the equipment and installation, the operating cost and the water heater use (DOE-OCS 1998c). The result, when applied to households in the *Residential Energy Consumption Survey* (DOE-EIA 1995), yields a distribution of the life-cycle costs for each design option.

The debate over admissible design options reached a climax over heat pump water heaters. Heat pump water heaters move heat from the air to the water and are significantly more efficient than electric resistance water heaters. Heat pump water heaters are dramatically more efficient in warm climates than electric resistance units but carry a significantly higher first cost. Because of the possible savings, in March 1994, the DOE published its intent to consider heat pump water heaters in the current rulemaking (DOE-EERE 1994). In January 1998, the DOE listed the design options it was considering for the final rule, and heat pump water heaters were not listed. Because of concerns over the "manufacturability, serviceability, and consumer utility, the department has screened out heat pump water heaters (DOE-OCS 1998c)." The AGA submitted comments to the DOE after the workshop contesting each of its reasons for eliminating heat pump water heaters from further consideration arguing that DOE's stated reasons were no longer true (Ranfone 1998). EEI's comments were terse: "DOE should not add any design options to the analysis. All of the design options that have been eliminated from further consideration should stay eliminated (Rosenstock 1998)." Condensing natural gas water heaters, which increase the efficiency of natural gas water heaters by condensing the water vapor in the flue gas, had previously been eliminated from consideration. The trade press has commented on these actions:

> To win the day, natural gas must praise the enemy – it must promote the most efficient electric water heater on the horizon. And electricity must do the reverse. Here's the idea: Convince the DOE that the most advanced technology for your opponent's water heaters is feasible and available. That forces the DOE to assign a higher minimum acceptable EF for your opponent, making him add high-tech features to his product line, forcing his price up. That should lead consumers and

> home builders to disdain your opponent's appliances – and instead buy yours (Radford 1999).

This effort on the part of the stakeholders is revealing; it implies that the industry believes that first cost is the primary determinant of fuel choice in water heaters and that it is even less likely that measurement basis of the EF will influence market share.

The life-cycle savings of any incremental change in a standard may be small, but the national savings in terms of pollution and load management can be quite large. The DOE projects the national environmental and energy conservation effects of the standard as part of the rulemaking. The advocates of source energy contend that the projected energy and environmental savings are biased against the use of natural gas since the standard is based upon a site-based EF and the DOE uses "emissions models that appear to severely under-account (if at all) for electric losses from extraction to generation whereas natural gas losses are accounted for from the point of extraction to the point of end-use (Krebs 1998)." The models that LBNL uses to estimate the emissions due to the implementation of the standard predict the fuel shifting and sales of the models in the future. LBNL estimates primary energy consumption with a conversion factor that is estimated through the National Energy Modeling System; the conversion factor changes over time and is consistent with the forecasts in the EIA's *Annual Energy Outlook* (DOE-EIA 1998b, 174-175). The conversion factor includes losses due to electrical generation, transmission and distribution and assumes that hydroelectric and renewable resources operate at full load. Predictably, site energy advocates also object to the use of a single conversion factor. "There is no benefit to 'saving' hydroelectric, wind, geothermal generation, or biomass BTUs. It is even more inappropriate to multiply these 'saved' renewable BTUs by a coal plant heat rate (Brundage 1998)." Also, "the key parameter of any future environmental impact will be based on the market choices made by customers, rather than the efficiency levels of the appliances used (Rosenstock 1998)."

4. Differences in the states

The site-based EnergyGuide labels have adorned water heaters for two decades, yet there is no evidence to suggest that the EF information or the use of the EF in general has had an effect on the fuel share in the national market for water heaters. Quite simply, the distribution of water heaters in each state varies greatly. Consider the four states for which data is available: California, Florida, New York and Texas. Figure 5 is the distribution of water heaters in these four states in 1993 (DOE-EIA 1995). Though the national standard for water heaters applies to units sold throughout the country, regional differences such as fuel availability, residential energy code, climate, and demand-side management policies can have a significantly greater effect upon the share of water heaters than national minimum efficiency standards.[7] We explore one aspect of the issue, state residential energy codes, on the distribution of fuels in the following chapter.

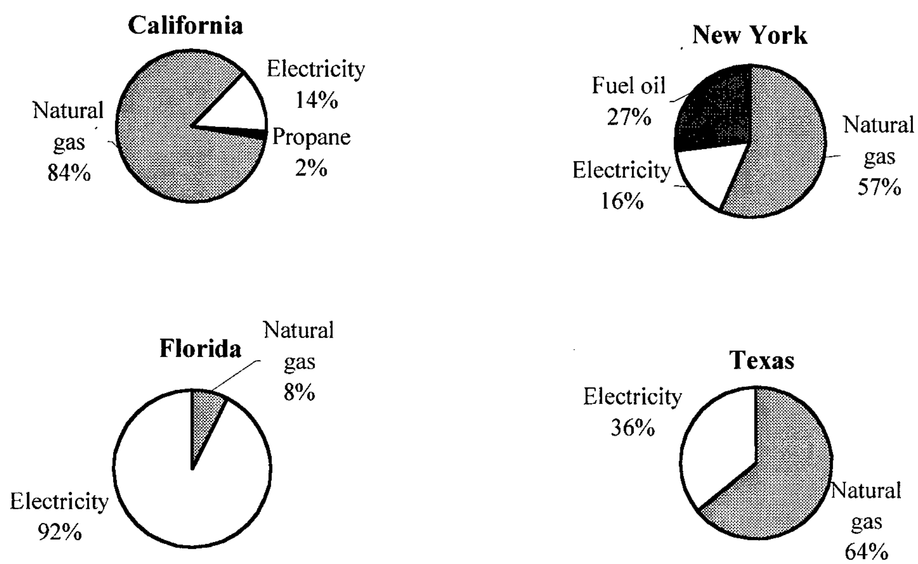

Figure 5. Distribution of water heaters in California, Florida, Texas and New York households by fuel type.

[7] California's residential energy code, Title 24, virtually precludes the installation of electric resistance water heaters.

III. Residential energy code analysis

1. Residential energy use and codes

The price of energy in the United States has been declining in real terms for over a decade. Figure 6 illustrates the price of energy in the residential sector from 1970 to 1995. The price of energy in the residential sector in constant 1995 dollars rose until 1983 and has dropped steadily since. In response to the energy crisis of the 1970s, many states implemented residential energy codes to stabilize or reduce their energy use. But the price of energy has not cooperated as a motivator for people to reduce their energy use and most states have seen their residential energy use rise in recent years.

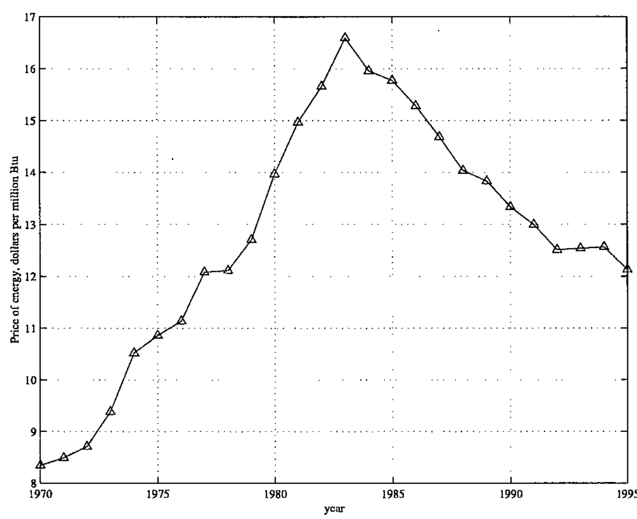

Figure 6. The price of energy in the residential sector in constant 1995 dollars per million Btu. The price is a weighted average of the price of all fuels consumed in the residential sector.

A residential energy code covers all aspects of the home related to energy use: equipment efficiency, insulation levels, placement of fixtures, etc. Through 1995, 37 states had implemented and enforced energy codes in the residential sector. Though more complicated than appliances, the measurement of energy in the home also falls into broad categories of site and source energy. Unlike the national water heater standards, there is considerable variation in the code stringency and enforcement level, and energy consumption patterns among the states, even among those in similar geographic and climate regions. Though the EPACT benchmarks state energy codes against the 1992 revision of the Model Energy Code (MEC), states often insert provisions unique to the state for political, economic or environmental purposes. Residential energy codes are much more difficult to evaluate than the minimum efficiency standard for a single appliance.

Energy efficiency is less of a primary concern in homes than it is in individual appliances. Builders and developers make decisions on their "perceptions of what will satisfy the consumer – both to sell the home initially, and to keep the consumer satisfied after moving in...Energy efficiency upgrades...are rarely offered, as some builders fear that offering such an upgrade will give consumers the impression that their base house is not energy efficient (U.S. Congress 1992, 74-75)." Also, "the perception that energy efficiency requires sacrifice is very persistent and acts as a significant barrier to wider use of energy efficient technologies (U.S. Congress 1992, 78)." Since a home can be considered to be a collection of energy consuming systems, consumer confusion at the appliance level propagates to the home.

During the negotiations over a national home energy rating system (HERS), stakeholder groups did voice their opinions on residential energy codes. Like the current debate over water heater standards, many of the stakeholder comments concerned site and source energy and revisited the same debate: that site or source energy put particular fuels at a competitive disadvantage. To address the stakeholder concern, we separate the 48 contiguous states into three categories: *group 1* states are those whose energy codes are site-based, largely based upon the MEC; *group 2* states are those that have source-based energy codes or codes that differentiate between fuels; *no code* states are those that did not implement or enforce energy codes before 1995. The division of states appears in Table 6 on page 46. The first part of the analysis quantifies the relationship between fuel share and changes in the fuel share for the *group 1* and *group 2* states. The second part of the analysis addresses the effects of residential energy codes upon energy efficiency in all classes of states. The rate of change of per-capita energy consumption in the residential sector and the percentage change in energy consumption since the late 1970s are the figures of merit that we use to evaluate the performance of state energy codes. By concentrating on relative changes in energy use, we are able to evaluate states against each other although the fuel utilization among the states may be much different.

Some definitions are required. By *fuel share*, we refer to natural gas or electricity sold in the residential sector normalized by the total energy sold in the residential sector on a Btu to Btu basis. These calculations rely upon the energy purchased by residential consumer – the site energy. Note that the total energy includes additional fuels such as oil and wood that we do not consider in the analysis. In the quantitative analysis, we renormalize by the sum of natural gas and electricity only. This notion of fuel share is different than the notion of market share promulgated in the previous section. In fact, energy suppliers refer to market share in the residential sector as the fraction of homes with natural gas or electric appliances. From a fuel-marketing standpoint, the notion is important, but from an energy efficiency standpoint, the distinction is irrelevant.

2. Natural gas and electricity share in the residential sector

To test the stakeholders' claim that the basis of measurement of a residential energy code results in a *de facto* preference for either natural gas or electricity, we have performed a quantitative analysis that appears in Appendix A.2. The methodology of the analysis is straightforward. For the three groups of states defined above, we identify a simple linear model to describe the changes in share of electricity (as a fraction of the electricity and natural gas used in the residential sector) in the states from 1970 to 1995 that takes into account the type of energy code (or lack thereof), the percentage of housing that complies with the code, the relative price of electricity to gas and the availability of gas.

The results of the quantitative analysis show that the share of electricity has been rising uniformly in the three sets of states and there is no statistical difference in the share of electricity and gas between the *group 1* and *group 2* states. Figure 7 is a plot of the share of natural gas and electricity in the three sets of states. While the reasons behind the uniform rise in electricity share are beyond the scope of this report, a reasonable conjecture is that it is due in part to the penetration of electric appliances in recent years that are not regulated by a residential energy code - especially air conditioning in many states - and in part to significant gains in efficiency of fossil-fuel equipment. While differences in electricity share do exist between states, as groups, there is no statistical difference in the fuel share in states that have site-based residential energy codes (*group 1*) and states that have source-based or fuel-specific energy codes (*group 2*).

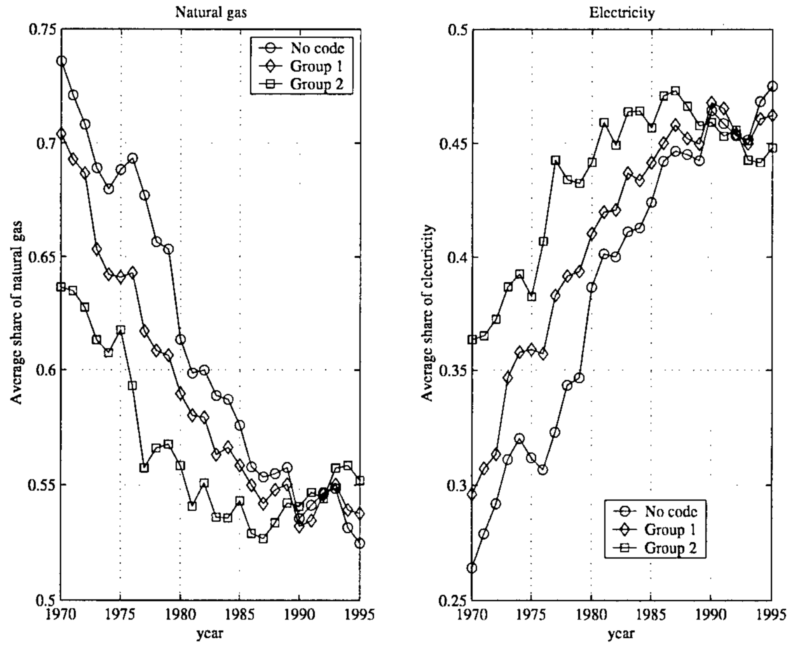

Figure 7. Average site-based share of natural gas and electricity in the *no code*, *group 1*, and *group 2* states from 1970 to 1995.

3. A preliminary look at the effectiveness of residential energy codes

The purpose of a residential energy code is not to equalize the market for either natural gas or electricity; it is to cost-effectively reduce energy consumption. Therefore, it is important to consider the performance of the codes as measured by the decline in per capita energy consumption and percent change in per capita energy consumption. Figure 8 is a plot of the average per capita energy consumption in the *group 1*, *group 2*, and *no code* states. The energy consumption refers to the total of all fuels used in the residential sector excluding transportation. The average level of annual per capita energy consumption among the three groups of states was within 3 million Btu per capita until 1985, after which the per capita energy consumption in the *group 1* and *no code* states rose and the per capita energy consumption in the *group 2* states remained roughly constant. In 1995, the average per capita energy consumption in the *group 2* states was 64 million Btu per capita, while the average per capita energy consumption in the *no code* and *group 1* states was 75 and 74 million Btu per capita respectively.

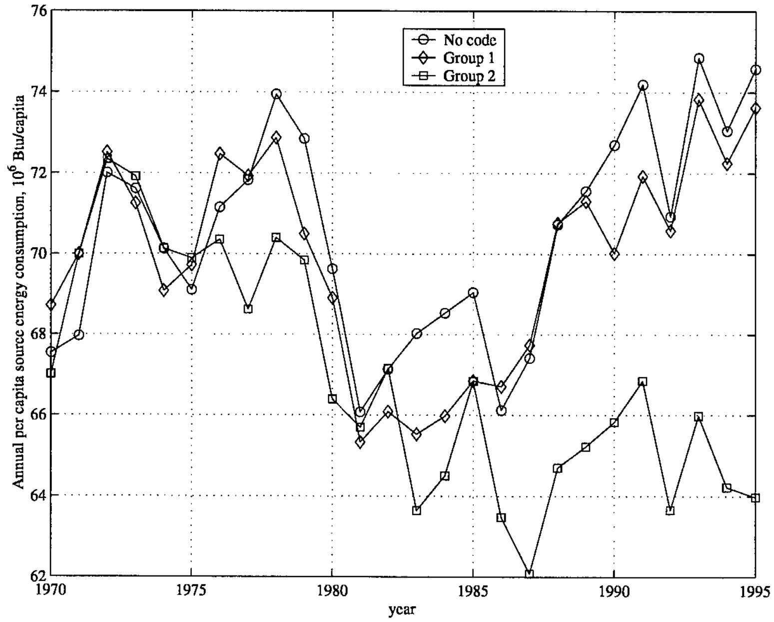

Figure 8. Average annual residential per capita energy consumption in the three sets of states. The energy includes all fuels consumed in the residential sector excluding transportation.

The analysis in Appendix A.3 supports the visual observation that the *group 2* states, as a group, maintained residential per capita energy consumption whereas the *no code* and *group 1* states, as groups, did not, with some caveats. First, the results are state-specific: for instance, there are *group 1* states that have energy efficiency performance equivalent to the performance of the *group 2* states - states that have stabilized or reduced residential per capita energy consumption from the level of the mid-1970s. Second, the analysis uses fuel-weighted prices of all energy consumed in the residential sector. A complete analysis, which is beyond the scope of this report, would be fuel-specific and would account for national and state legislation, utility-sponsored efficiency programs, equipment efficiency, building techniques, types, sizes and location among other factors. With those concerns noted, the analysis indicates that there exist substantive differences in the change in per capita energy consumption and that these differences are distributed roughly by the state grouping. The analysis is not causal and additional research is necessary to determine the instigators of change of energy efficiency in the residential sector.

We identify those states that outperform their peers in gains in residential energy efficiency. The figures of merit are the percent decline in per capita energy consumption from the average per capita energy consumption of the mid-1970s (the years preceding the implementation of most of the energy codes) and the annual rate of decline of per capita energy consumption in the residential sector since energy code implementation. A list of these states appears in Table 2.

State	Year of residential energy code implementation	Average annual rate of change of per capita source energy consumption calculated from the year of energy code implementation to 1995, 10^6 Btu per capita per year.	Percent change in per capita source energy consumption from 1970-1978 average to 1988 to 1995 average.
CA	1978	-0.49	-19.2
UT	1986	-0.87	-13.2
NV	1975	-0.32	-9.9
MA	1978	-0.16	-12.8
OR	1978	-0.09	-6.2
WA	1975	-0.27	-5.4

Table 2. States with declines in residential per capita energy consumption from levels in the 1970s and negative rates of change of residential per capita energy consumption.

4. Formulating effective residential energy efficiency policy at the state level

> Not later than two years after the date of the enactment of the Energy Policy Act of 1992, each State shall certify to the Secretary that it has reviewed the provisions of its residential building code regarding energy efficiency and made a determination as to whether it is appropriate for such State to revise such residential building code provisions to meet or exceed CABO Model Energy Code, 1992 (EPACT 1992, 304(a)(1)).

The EPACT is very clear with respect to the minimal state efforts for building energy efficiency. To aid in the adoption of this provision, the Alliance to Save Energy, the American Council for an Energy Efficient Economy and the Natural Resources Defense Council established the Building Codes Assistance Project (BCAP) to monitor the progress of the states' efforts in the adoption and enforcement of energy codes. The progress of the states is measured against adoption of the 1992 and 1995 revisions of the Model Energy Code. The 1998 revision of the Model Energy Code is the International Energy Conservation Code, which promises to offer an "international forum for energy professionals to discuss performance and prescriptive code requirements (ICC 1998)." Table 3 contains data on the current status of energy codes as benchmarked against the Model Energy Code, its successor, or equivalent.

Energy code or equivalent	States
Exceeds 95 MEC statewide	CA, FL, OR, MN
Exceeds 95 MEC in some jurisdictions	AK, WA, WI
Mandatory statewide adoption of 95 MEC	GA, MD, MA, NC, NH, RI, SC, OH, VA, VT, UT
Partial adoption of 95 MEC	OK, LA, HI
Mandatory statewide adoption of 93 MEC	DE
Partial adoption of 93 MEC	TX, ND, MT, AL, KS
Mandatory statewide adoption of 92 MEC	AR, IN, IA, KY, NM, TN
Partial adoption of 92 MEC	NY

Table 3. State energy codes as benchmarked against the Model Energy Code and its equivalents. (BCAP 1999).

The uniformity of the energy codes among the states has been lauded and denigrated. According to the International Code Council, the organization that developed the 98 IECC, the promulgation of uniform codes allows builders to broaden their markets (ICC 1999). There are those who do not believe that a common energy efficiency code will promote greater competition in the building industry; rather they see the movement as a blatant attempt by the electric industry to install codes favorable to the use of electricity. Regarding the update of the ASHRAE 90.1 standard – which the MEC references for commercial buildings, one natural gas industry representative writes: "How can ASHRAE tout 'consensus' when its committees are skewed with representation from electric utilities, manufacturers and electric allied organizations that attempt to rule by majority (Krebs 1999)?" The previous analysis suggests that the adoption of the MEC or the IECC is not likely to cause a shift from gas to electricity. On the other hand, the analysis in this section implies that a uniform code may not result in reduced energy use.

The analysis of Appendix A.3 shows that California has the third highest percentage drop in residential per capita energy consumption and third fastest decline in residential per capita energy consumption since energy code implementation. It is for this reason that we consider California for a case study of the successful implementation and enforcement of a residential energy code.[8] Title 24, California's building energy efficiency code, is unique. A new residence in California must meet a set of mandatory features and also comply with "either the performance standards (energy budgets) or the prescriptive standards (alternative component packages) set forth in this section for the

[8] Oregon, Massachusetts, Nevada and Utah are four states in addition to California with similar residential energy efficiency behavior. Future investigations regarding state level energy efficiency policy should begin with an examination of energy efficiency policy in these states and state-specific trends in economic growth, population growth, housing and other factors.

climate zone in which the building will be located (CEC 1995b, 124)." While the MEC also has a performance compliance path, California has installed an infrastructure to make the energy budget method the easiest and most flexible method of compliance. The performance is simple: "A building complies with the performance standard if its combined calculated depletable energy use for water heating and space conditioning is less than or equal to the combined maximum allowable energy use for both water heating and space conditioning, even if the building fails to meet either the water heating or space conditioning budget alone (CEC 1995b, 124)."

It is not clear that Title 24 alone has led to the increases in residential energy efficiency in California. Title 24's provisions for enforcement, its self-evaluation, its flexible approach to compliance and the California Energy Commission's (CEC) education programs coupled with demand-side management programs and the availability of cost-effective technologies also play a role in reducing energy consumption. The enforcement agency that is responsible for issuing the building permit must review the plans and specifications to determine code compliance before issuing the building permit. The same agency must inspect the building during and after construction to ensure compliance with the code. Various state and local agencies are required to perform the inspections depending on the building type. Because a large proportion of homes in California choose to use the performance-based approach to code compliance, the accuracy of the computer models is essential. In 1995, the CEC published the results of a study to determine the actual energy usage characteristics of homes constructed under the 1993 revision of Title 24. The results of the study were used to modify the assumptions in the computer models so that the compliance calculations more closely resembled the actual energy usage in the homes (CEC 1995a). The consistent evaluation and updating of the models used to perform compliance calculations guarantee that the performance-based approach remains the primary choice for builders and homeowners. Finally, California requires that the code compliance certificates and information on the proper operation of the energy consuming systems in a home be distributed to the homeowner or the person responsible for their operation at the time of sale (DOE-OBT 1998). In addition to the CEC sponsored programs, California, like many other states, may have also benefited from utility-sponsored rebates, demand-side management programs in addition to state-specific events and trends.

5. Summary of residential energy code analysis

Differences in the residential share of electricity between the group of states with source-based or fuel-specific energy codes and the group of states with site-based energy codes are negligible. Evidence to support the claims of the stakeholders that the basis of the measurement of energy used for compliance with the code adversely affects the market for natural gas or electricity does not seem to exist. Additionally, those states with source-based or fuel-specific energy codes have maintained a level of residential energy productivity as opposed to their peers with codes modeled after the MEC or states without statewide residential energy codes (when considering the percent change in residential per capita energy consumption from historic levels). It is important to recognize that every state is unique and that there exist several methods for promoting residential energy efficiency. Future studies should address in-depth the plurality of factors that have contributed to the changes in energy consumption and the interactions of the policy options available at the state level.

IV. Conclusions and implications for the DOE

1. Quantitative results

Stakeholder concerns outlined in Chapter I and discussed in Chapters II and III center on the possible market shifting effects of DOE and state policy based on either site or source energy measurements. The policies, stakeholders claim, change the availability of certain products and services and furnish consumers with misleading information such that ill-informed decisions regarding energy are made. We summarize the quantitative results.

- We have found no statistical evidence to support the claim that the FTC EnergyGuide label, associated codes and ratings, or the upcoming DOE standard, have disturbed or will disturb the balance of natural gas and electric water heaters in that these policies are based upon site energy.
- Statistical differences in the utilization of electricity between states with source-based residential energy codes or codes that differentiate between fuels, and states with site-based codes are negligible.
- Measured in terms of per capita energy use in the residential sector, there is a wide range of performance of the states. As a group, states with residential energy codes based upon source energy or those that differentiated between primary heating fuel have on average maintained or reduced their levels of residential per capita energy consumption when compared to states with site-based energy codes or no energy codes. There do exist states with site-based energy codes and states with no energy codes that have either maintained or reduced per capita energy consumption. Additional analysis needs to be performed to determine the state level initiatives that contribute to reduced energy consumption in the residential sector.
- The states in *group 1*, by and large, are those states whose energy codes are based upon the Model Energy Code. Given the variation in energy performance in these states, it is unclear that the current effort to encourage adoption of the MEC as a minimum standard for residential energy codes will be successful in reducing residential per capita energy consumption.

2. Implications

Consumer behavior with respect to energy efficiency remains poorly understood and the proper set of information to furnish consumers remains an enigma. The analyses in Chapters II and III considered aggregate national- and state-level effects of energy policy; isolated examples of counterproductive energy decisions based upon single measures of site or source energy. For example, if a site-based energy performance standard were to encourage the change of a natural gas central heating system to electric resistance, the result in most regions of the country would be increased cost of operation and increased emissions of greenhouse gases; the result would be more pronounced in regions that rely heavily upon coal-fired electricity generation. In California, the source-based residential energy code is uniformly applied such that in locations where gas is unavailable, builders must install propane water heaters to meet the requirements of the code. It is not clear that the result is consistent with the intent of California policy given the costs of transporting the propane and the penetration of renewable resources in the region. The reliance upon a single measure of the consumption, costs or effects of energy use in a large and diverse region carries with it the possibility for unintended consequences. Therefore, a single piece of information, such as the energy use (source or site) or annual operating cost is insufficient to transmit the energy efficiency and cost information (that the consumer may want to know) and the environmental information (that the DOE would like the consumer to consider). As a result of the analysis in Chapters II and III, the DOE may wish to consider alternate policies that would include additional energy consumption, cost, and environmental information without the expectation of distorting the aggregate market for specific fuels.

The analysis highlights differences in the states with respect to residential energy consumption and efficiency performance. It identifies an opportunity for the DOE to promote and facilitate state-based programs for energy efficiency: for example, the DOE may wish to encourage and facilitate communication between states, to provide resources for code adoption and enforcement, and to disseminate information to the states on the benefits of increased energy efficiency. Additional analysis with respect to specific drivers of energy efficiency is necessary.

The stated goals of the DOE and the goals of the recent Executive Order regarding federal energy management include increased energy efficiency, life-cycle cost effectiveness, and reduced emissions due to energy use. Our conclusions support the available literature, which suggests that if the DOE is to encourage these goals nationally, it should seek to furnish consumers with a simple-to-understand set of information regarding energy use rather than a single measurement.

Currently, changes in DOE policy occur in an environment of energy deregulation. The hope is that a result of deregulation and restructuring in the energy industries will be increased value and choices, in addition to reduced prices. Value may be measured in terms of service and reliability, and choices may include the option to purchase renewable energy or fee structures that meet different consumer needs. Legislation does not bind the DOE regarding policy based upon consumer costs, including an adjustment of test procedures to reflect actual usage, and environmental information.

It is the stated policy of the DOE to encourage the development of a competitive market for electricity with reduced environmental impacts (DOE 1997, 13). Chapter III demonstrated the sensitivity of natural gas and electricity use with respect to price. Given the interplay of natural gas and electricity in the residential sector, natural gas and other fuels are integral to the development of the market for electricity, and should be reflected in DOE policy.

A. Quantitative methodology

1. Water heater market modeling and analysis

Have the DOE's site-based policies on water heaters caused a distortion in the market for gas and electric units? The policy to label water heaters has been in effect since 1979 (U.S. Congress 1992, 113), certainly enough time to influence the market. The aggregate national market is appropriate for the analysis since the DOE policies are national in scope.

The AGA claims that the DOE's policies favor electric units over natural gas units. We test the validity of this claim through the analysis of shipment data and the identification of a simple model that relates the information that consumers receive about water heaters with the shipments of water heaters. The set of customers includes builders and contractors as well as homeowners. We assume that consumers react to the EF of electric and natural gas units and to the operating cost information provided on the EnergyGuide label. We would have preferred to include first cost of the units in the model as well; the data for purchase price and installation cost, however, do not change in constant dollars over time and cannot be included in an empirical model. Also, the data for shipments do not differentiate between replacement units and new installations. Our data source is the Gas Appliance Manufacturers Association shipment data as compiled and organized by the Lawrence Berkeley Laboratory.[9]

The mathematical model that we will identify postulates that relative shipments of electric to gas units is a function of the relative EF and the relative operating cost of the units and has the following form.

$$\frac{U_{elec}}{U_{gas}} = \alpha_0 \left(\frac{EF_{elec}}{EF_{gas}}\right)^{\alpha_{EF}} \left(\frac{C_{elec}}{C_{gas}}\right)^{\alpha_C}$$

U denotes the number of shipped units, EF denotes the energy factor, and C denotes the operating cost. The alphas are the parameters to be estimated: α_0 is the baseline relative share, α_{EF} is the exponent corresponding to the relative energy efficiency and α_C is the exponent corresponding to the relative operating cost. The model quantifies the variations in the relative shipments to variations in the relative energy factor and operating cost. We expect the relative shipments to be negatively correlated with the relative operating costs of the units. If the claim of the AGA is true - that the site-based policies favor electric units over natural gas units - then the relative shipments of electric to gas water heaters will be positively correlated to relative changes in the EF.

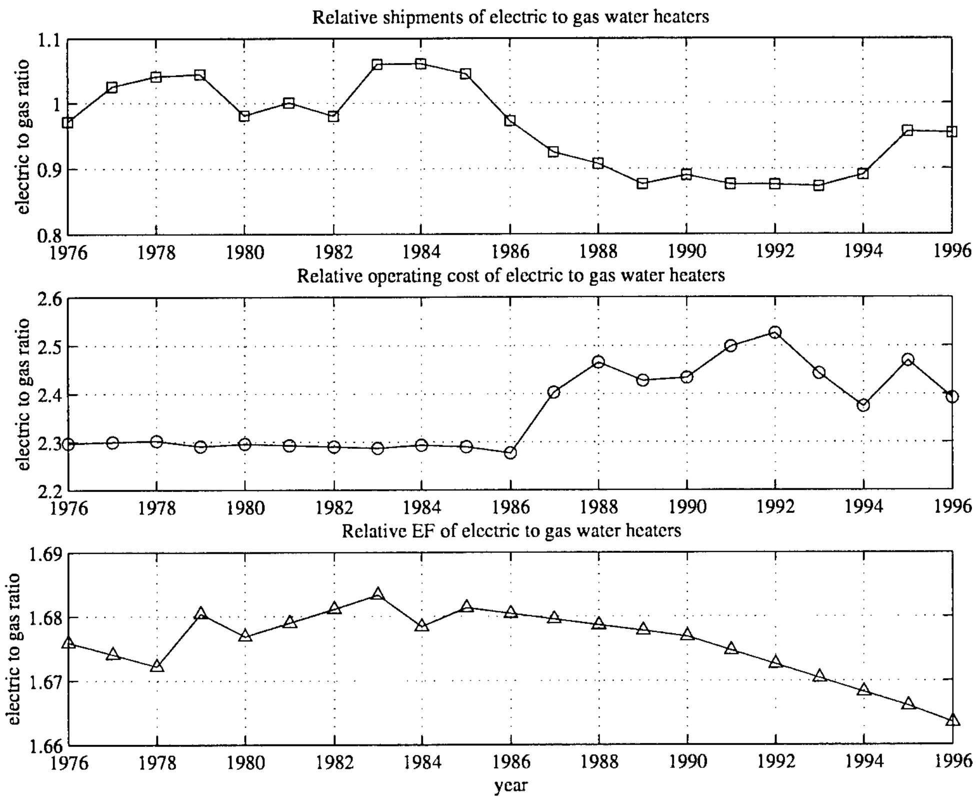

Figure 9. The relative shipments, energy factor and operating cost of electric to gas water heaters from 1979 to 1996.

Figure 9 displays the data for relative water heater shipments, EF and operating cost. Before we identify the model, we note several limitations in the data. There are only 18 data points corresponding to the 18 years of interest. The small number of data points makes it difficult for us to make strong conclusions based on the results of the parameter identification. While there is variation in the relative EF, the magnitude of that variation has been very small: over the years of interest, the magnitude of the total change in

[9] There do exist additional sources of data regarding water heater sales and penetration by type. However, we were unable to validate them against published and verified data.

relative energy factor has been 1.2 percent. Conclusions based upon the relative energy factor assume market sensitivity to energy efficiency: an assumption that is called into question by studies of consumer behavior. The results are also subject to numerical instability.

Descriptive statistics can be helpful in interpreting the data. There is some correlation[10] between the relative shipments and the relative EF and relative operating cost, which is summarized in Table 4. Indeed, shifts in the relative energy factor correspond to shifts in the relative number of shipments. However, there is a much stronger correlation between shifts in the market and shifts in the relative operating cost. The correlation between relative shipments and relative EF is weak while the correlation between relative shipments and relative operating cost is strong.

Independent variable	Correlation coefficient
Relative energy factor, electric to gas	0.50
Relative operating cost, electric to gas	-0.79

Table 4. Correlation coefficient between the ratio of shipments and the relative energy factor and relative operating cost for electric and gas water heaters from 1979 to 1996.

Parameter	Coefficient	Standard Error.
$\mathrm{Ln}(\alpha_0)$	1.80	3.64
α_{EF}	0.41	2.06
α_C	-0.65	0.13
Adj. R^2		0.65

Table 5. Results of model identification for relative changes in the national water heater market.

Table 5 contains the model's identified parameters and their standard errors. Given the arguments stated above, conclusions based upon the parameters identified in Table 5 are weak. The parameter corresponding to the relative EF is positive, indicating that increased shipments of gas water heaters have accompanied declines in relative EF. However, the t-ratio of this parameter is 0.199, giving us little confidence that this parameter is different from zero. The parameter corresponding to the operating cost is negative with a t-ratio of 5. The data show that increases in the relative operating cost of electric to gas water heaters have been accompanied by decreases in the relative shipments of electric to gas water heaters. The error associated with this parameter is sufficiently small that we can identify its effect as statistically significant. Again, there is

[10] For the random variables *X* and *Y*, the correlation coefficient of *X* and *Y* is a statistical measure of the "extent to which *Y* can be predicted by a linear function of *X* (Leon-Garcia 1994, 234)."

little variability of relative EF over time and no statistically significant effect of the relative EF on the relative shipments.

2. Electricity share modeling and analysis

States with site-based residential energy codes			States with source-based or fuel-differentiated residential energy codes	States with no mandatory statewide residential energy codes	
	Group 1		*Group 2*	*No code*	
AR	ME	NV	CA	AL	MO
CT	MI	OH	NY	AZ	ND
FL	MN	PA	OR	CO	OK
GA	MS	RI	WA	DE	SD
IA	MT	SC	WI	IL	TX
ID	NE	TN		KS	VT
IN	NC	UT		LA	
KY	NH	VA			
MA	NJ	WV			
MD	NM	WY			

Table 6. Groupings of states by residential energy code through 1995. (DOE-OBT 1998).

Table 6 partitions the states into the three categories we use in the study: *group 1, group 2,* and *no code*; Figure 1 on Page xvi is a map shaded to indicate the three categories. The years of interest for this study are 1970 through 1995. In grouping the states together, we make imperfect assumptions regarding the basis of the code, the level of code stringency, and the enforcement of the code. Only California has a source-based code. California's Title 24 states that buildings shall be "designed, constructed and installed to use no more source energy from depletable sources than the energy budget (CEC 1995b, 73)."[11] Several other states have requirements for homes that are heated with electricity that require more efficiency than homes that are heated with natural gas, oil or wood: New York, Oregon,[12] Washington and Wisconsin. These five states often have provisions for compliance based upon the total building performance rather than individual component performance. The Florida Energy Efficiency Code, though performance-based, does not differentiate between fuels and hence we categorize it among the *group 1* states. We use the data of Table 6 along with the year of code implementation to quantify the effect of the code. The data source for the state

[11] The quotation comes from the section of Title 24 that covers "nonresidential, high-rise residential, and hotel/motel occupancies." It is used in this context because it is the most succinct statement of the source-based methodology.

categorization is the December 1998 "Status of State Energy Codes" report published by the DOE Office of Building Technologies.

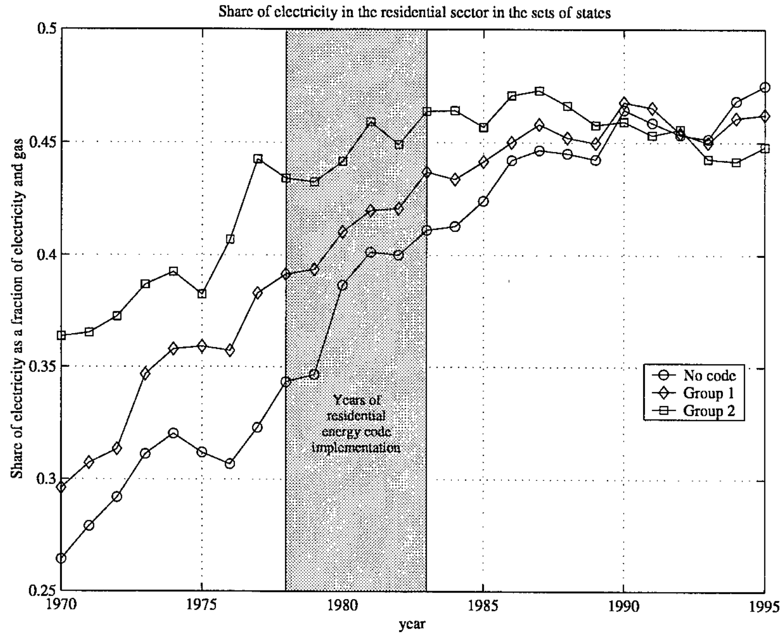

Figure 10. Average electricity use as a fraction of electricity use and natural gas use.

For this analysis, we are interested in the share of electricity normalized by the total shares of electricity and natural gas in each state. We will determine if there is a correlation between the energy code and the share of electricity while accounting for various factors. It is the claim of the stakeholders that the energy codes promulgated in the *group 1* states favor the use of electric equipment and that the energy codes promulgated *group 2* states favor the installation of natural gas equipment. The *no code* states will serve as a baseline. The fuel consumption data comes from the *State Energy Data Report, 1996* and the fuel price data comes from the *State Energy Price and Expenditure Report, 1995*, both published by the DOE Energy Information Administration.

Before we engage a detailed mathematical identification, we look at the electricity share in the three sets of states for patterns. Figure 10 is a plot of the average value of the electricity share in the three sets of states from 1970 to 1995. Inspection of Figure 10 is the first step in assessing the claims of the stakeholders with respect to effects of the

[12] The most recent Oregon code has the same provisions for homes heated with gas or electricity.

energy measurement on the fuel share. The stakeholders claim that the *group 1* states tend to favor the use of electricity whereas the *group 2* states tend to favor the use of natural gas. Figure 10 shows that the difference in electricity use in the *group 1* and *group 2* states has narrowed from 7 percent in 1970 to less than 2 percent in 1995. The astute observer may notice that the share of electricity grew from 0.30 to 0.45 in the *group 1* states and from 0.36 to 0.44 in the *group 2* states in that time period. It would be incorrect to interpret this change as a preference for electricity in the *group 1* states: most of the rise in electricity share occurred before the early 1980s, the years of implementation of energy codes. In fact, since the mid-1980s, the share of electricity in the three sets of states has varied little on average.

The shaded years in Figure 10 are 1978 through 1983: the years in which most states adopted energy codes. A reasonable conjecture is that the states in any particular group had common characteristics that led to the adoption of a code that we have classified as *group 1* or *group 2*. Such characteristics may include pronounced differences in the rate of growth of new housing, the growth rate of state GSP, or the share of electricity (or natural gas) in the states in those years. Figure 11 is a histogram of the average growth rate of new housing in the state groups from 1980 to 1983.[13] The distribution for each group of states is relatively broad, though the growth rate in the *group 2* states is smaller that that of many of the *group 1* and *no code* states.

However, in the years of interest, Oregon did differentiate between the two fuels.

[13] The readily available data for housing units from the U.S. Census Bureau spans the 1980 census to the present.

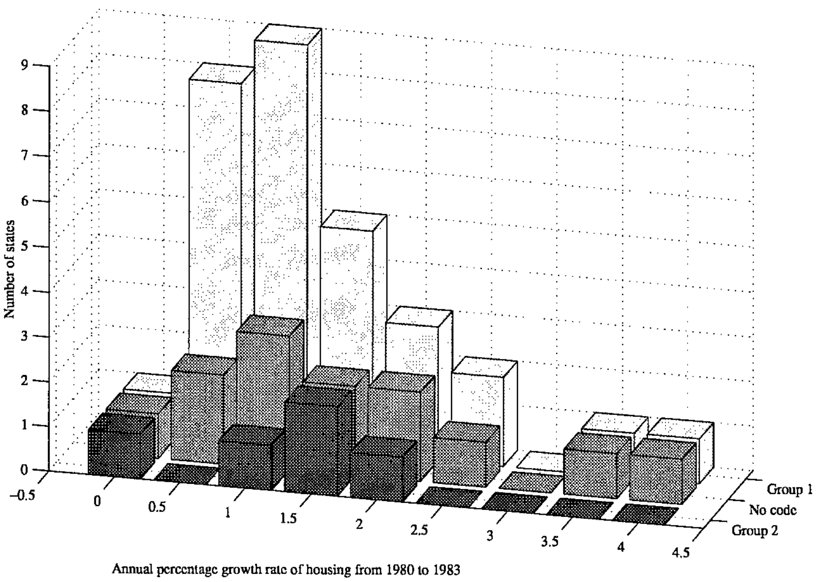

Figure 11. Histogram of the annual percentage growth rate in residential housing from 1980 to 1983 by state group.

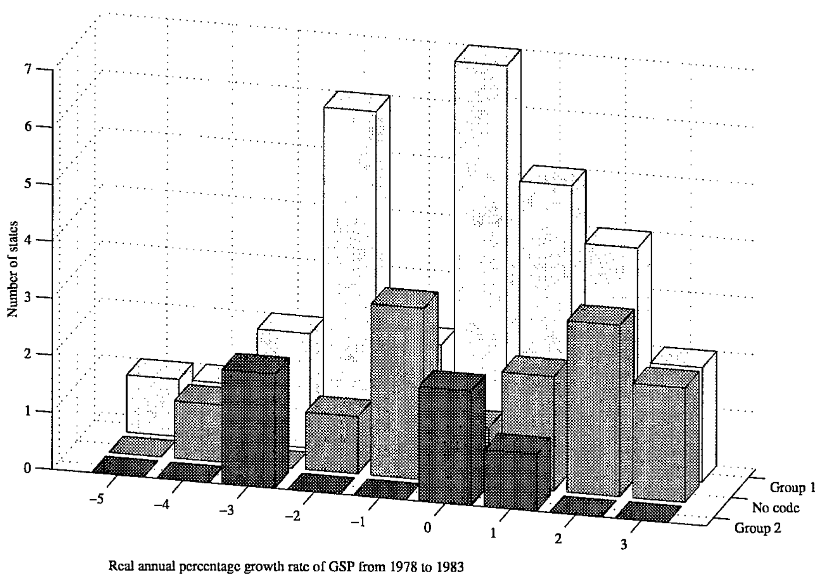

Figure 12. Real annual percentage growth rate of GSP from 1978 to 1983 by state group.

Energy use and economic growth are intimately related and the decision in some states to enact energy codes may have been in part due to the economic condition of the state. Figure 12 is a histogram of the real annual percentage growth rate of GSP. No state group has a distinctive pattern with respect to the growth rate of its GSP.

Energy codes are the result of a political process and can reflect the energy use characteristics of the state and the home construction techniques present at the time of adoption. Therefore, consider the share of fuels in the states during years corresponding to the adoption of codes. Figure 13 is a histogram of the average share of electricity (as a fraction of electricity and gas) in the years 1978 to 1983. As in the case of the distribution of the growth rate of new housing and the growth rate of the GSP, the distribution of electricity shares in these years is broad in each state group.

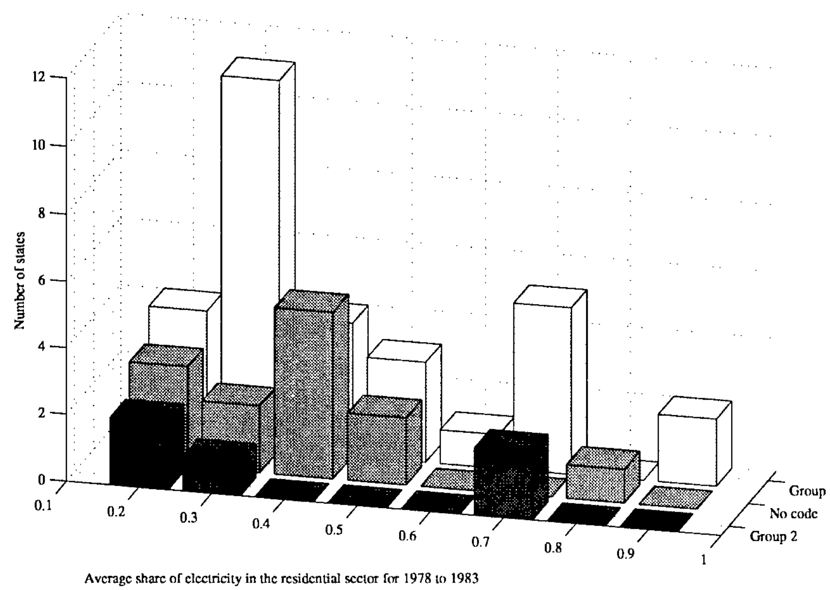

Figure 13. Average share of electricity in the residential sector in the three groups of states from 1978 to 1983.

Figure 14 is a histogram of the electricity share averaged over the years 1992 to 1995. Table 7 contains the data used to generate the histogram. Figure 14 allows us to inspect the distribution of electricity share in the groups of states after approximately a decade of energy codes. Three of the five *group 2* states have shares of electricity that are low (0.3) compared to the other states. However, two of the *group 2* states – Oregon and Washington – have high electricity shares (0.7). The price of electricity in these two states is significantly lower than the national average, implying that prices for fuels play a strong role in the share of fuels used in those states. Of the 30 *group 1* states, 12 states have shares of electricity equal to or less than the low shares of electricity in the *group 2* states, including California. Two of the *group 1* states – Florida and Maine – have electricity shares of approximately 90 percent. The situation may be due to the local unavailability of natural gas in both Florida and Maine, Maine's use of wood and oil for heating, and Florida's heavy air-conditioning load. The share of electricity in the *no code* states varies from 20 to 70 percent and the distribution is relatively flat.

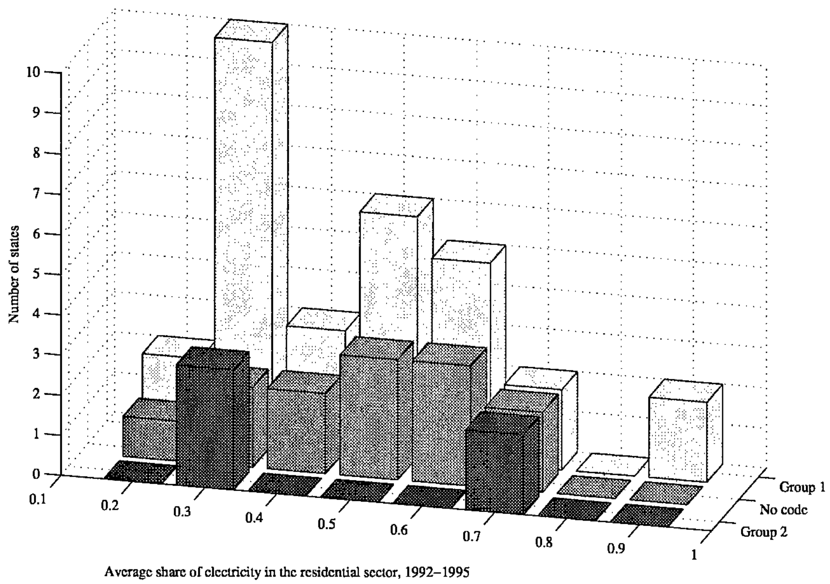

Figure 14. A histogram of the average share of electricity from 1992 to 1995 in the three groups of states.

Group 2 states	Average share of electricity, 1992-1995	Group 1 states	Average share of electricity, 1992-1995	Group 1 states	Average share of electricity, 1992-1995	States with no energy codes	Average share of electricity, 1992-1995
CA	0.32	AR	0.48	NC	0.73	AL	0.60
NY	0.26	CT	0.46	NE	0.36	AZ	0.67
OR	0.66	FL	0.95	NH	0.64	CO	0.26
WA	0.66	GA	0.50	NJ	0.26	DE	0.54
WI	0.31	IA	0.32	NM	0.30	IL	0.20
		ID	0.63	NV	0.51	KS	0.31
		IN	0.35	OH	0.28	LA	0.58
		KY	0.49	PA	0.34	MO	0.39
		MA	0.31	RI	0.30	ND	0.50
		MD	0.48	SC	0.74	OK	0.43
		ME	0.93	TN	0.64	SD	0.47
		MI	0.19	UT	0.24	TX	0.57
		MN	0.30	VA	0.62	VT	0.73
		MS	0.62	WV	0.44		
		MT	0.38	WY	0.34		
Mean	0.44	Mean			0.47	Mean	0.48
Standard deviation	0.20	Standard deviation			0.20	Standard deviation	0.16

Table 7. The 1992 to 1995 average of the share of electricity in the three sets of states.

Fuel shares and fuel prices are closely related. There is a strong negative correlation between the relative price of electricity to natural gas and the relative share of electricity to natural gas in the three sets of states from 1970 to 1995 (see Table 8). The average correlation between relative fuel share and relative energy price among the states is within 0.05 in the *group 1* and *group 2* states. It is also strongly negative for most states, suggesting that price is a strong driver of fuel share in the residential sector.

Group 2 states	Correlation coefficient	Group 1 states	Correlation coefficient	Group 1 states	Correlation coefficient	States with no energy codes	Correlation coefficient
CA	-0.7315	AR	-0.8905	NC	-0.6970	AL	-0.8706
NY	-0.7512	CT	-0.6150	NE	-0.8908	AZ	-0.8219
OR	-0.6056	FL	-0.4678	NH	0.0252	CO	-0.8724
WA	-0.5649	GA	-0.7578	NJ	0.0264	DE	-0.7280
WI	-0.9042	IA	-0.9110	NM	-0.8605	IL	-0.4329
		ID	-0.7333	NV	-0.5307	KS	-0.8170
		IN	-0.8846	OH	-0.8509	LA	-0.7120
		KY	-0.9199	PA	-0.7864	MO	-0.8027
		MA	-0.3709	RI	-0.0068	ND	-0.8560
		MD	-0.6828	SC	-0.9067	OK	-0.8633
		ME	-0.6564	TN	-0.3763	SD	-0.9174
		MI	-0.5258	UT	-0.8578	TX	-0.7554
		MN	-0.8365	VA	-0.7825	VT	-0.6968
		MS	-0.6877	WV	-0.8608		
		MT	-0.8823	WY	-0.8794		
Mean	-0.7115	Mean			-0.6686	Mean	-0.7805
Standard deviation	0.134	Standard deviation			0.2807	Standard deviation	0.1249

Table 8. Correlation coefficients of relative price of electricity to natural gas and relative share of electricity to natural gas for the years 1970 to 1995.

The mathematical model that we use to determine the relationship between the fraction of electricity in a set of states and the type of residential energy code is a simple linear model that takes into account the relative price of electricity to natural gas, the availability of natural gas and the percentage of housing units that comply with the energy code. Ordinary least squares is the identification procedure. The dependent variable is the share of electricity normalized by the share of electricity and natural gas only: $\sigma_e/(\sigma_e+\sigma_g)$. The results also quantify the effects of the code regimes on the share of natural gas through the identity $\sigma_g/(\sigma_e+\sigma_g) = 1- \sigma_e/(\sigma_e+\sigma_g)$. The model that we identify is

$$\frac{\sigma_e}{\sigma_e + \sigma_g} = \beta_0 + \beta_P \frac{P_e}{P_g} + \beta_G \frac{G}{N} + \beta_t t + \beta_1 C_1 + \beta_2 C_2 + \beta_{1t} C_{1t} + \beta_{2t} C_{2t}$$

The independent variables are P_e/P_g, the relative price of electricity to gas, G/N, the number of gas customers normalized by the population, t, time, C_1, a period-specific dummy variable representing a *group 1* code, C_2, a period-specific dummy variable representing a *group 2* code, C_{1t}, the fraction of housing in a *group 1* state that complies with the code, and C_{2t}, the fraction of housing in a *group 2* state that complies with the code. The parameters to be identified are β_0, the constant term, β_P, the parameter representing the effect of the relative price, β_G, the parameter representing the effect of the availability of natural gas, β_t, a term that captures trends over time, β_{C1} and β_{C2}, parameters representing the presence of a *group 1* or a *group 2* energy code respectively, and β_{C1t} and β_{C2t}, terms that represent the effect of the percentage of housing built in accordance with a *group 1* or *group 2* energy code. The *no code* states are the baseline: the model quantifies deviations from this baseline due to the listed factors. For simplicity, we have omitted the noise input and notation for each state and year from the equation. The data is time-series panel data including the years 1970 through 1995 for the 48 continental states.

The availability of natural gas and the post-code housing are variables that are derived from available data. The EIA's *Historical Natural Gas Annual* contains data on the number of residential natural gas customers in a state. To derive an estimate of the availability of natural gas in the state, we normalize the number of natural gas customers by the population of each state in each year. The number of housing units in a particular state could make a tighter estimate, but the data on housing units is not readily available for the years of interest. Since the number of persons to household/housing unit is approximately three, the effect of the availability of natural gas on the share of electricity, as described by β_G, will be overestimated by approximately a factor of three. Since the housing built in compliance with a code is that which should, if the claim of the stakeholders is true, reflect the distortion in the market for a particular fuel; the percentage of housing in a state that is post-code is therefore a key variable in the analysis. Since state-by-state data on housing starts are unavailable, we use the number of housing permits issued per state as a proxy. We normalize the sum of the housing permits issued since code implementation by the number of total housing units to estimate the percentage of housing that complies with the code. In states in which the energy code was implemented before 1980, we extrapolate the percentage of code compliant housing from 1980 to the year of code implementation. It is this variable that we will use to check the effect of the residential energy code on the fuel share.

What do we expect from the identification? Since the model quantifies the share of electricity in the states, we expect the constant term to be positive, representing a baseline level for the share of electricity. The correlation coefficients in Table 8 indicate that the coefficient representing the effect of the relative price of electricity to gas on the share of electricity should be negative. The share of electricity should be negatively correlated to the availability of natural gas in a state. Since the share of electricity has been steadily rising (see Figure 10), we expect the coefficient corresponding to unobserved secular effects to be positive. The coefficients β_{C1} and β_{C2} represent the initial effect of the code on the fuel share, β_{C1t} and β_{C1t} represent the cumulative effect of the code. We will formulate hypothesis tests based upon these coefficients.

The results of the parameter identification along with their standard errors appear in Table 9. As predicted, the coefficient for the constant term is positive. The coefficient of the relative price of electricity to gas is negative.[14] The coefficient corresponding to the availability of natural gas is negative as well; its value is -2.191. As mentioned above, the magnitude of this coefficient is overestimated by approximately a factor of three.

Independent Variable	Coefficient	Standard Error	White Standard Error
β_0	0.856	0.011	0.032
β_P	-0.025	0.002	0.005
β_G	-2.191	0.038	0.175
β_t	0.007	0.000	0.001
β_{C1}	-0.057	0.007	0.019
β_{C2}	-0.065	0.016	0.047
β_{C1t}	0.116	0.042	0.114
β_{C2t}	0.327	0.134	0.241
Adjusted R^2		0.844	

Table 9. Results of electricity share parameter identification and standard errors.

[14] The availability of gas at the time of construction, the first-cost of gas installation – which can be very expensive compared to electricity – and the regional characteristics of energy use dominate the decision to install natural gas in a home, though the relative price of electricity to gas can also play a role. An appropriate way to augment the model to account for this decision-making process would be to include gas availability at the time of home construction as an independent variable: data does not exist to support such an analysis. At the very least, the model does not consider fully the effect of the relative price on the share of electricity to gas. Recognizing this omission, we have identified the model while omitting price as an independent variable. The remaining parameters change little with respect to the full model and the interpretations with respect to the parameters representing the presence of energy codes remain the same.

The coefficients corresponding to the implementation and progression of the residential energy codes are those that concern us the most. We note that the behavior in the *group 1* and *group 2* states, as characterized by the values of the coefficients, is qualitatively the same. The initial effect of the codes, represented by β_{C1} and β_{C2}, is negative and the cumulative effect, represented by β_{C1t} and β_{C2t}, is positive. Curiously, the coefficient corresponding to the percentage of housing that complies with a code is larger for the *group 2* states than for the *group 1* states: the code-compliant housing stock in the *group 2* states corresponds to a greater increase in the share of electricity than the code-compliant housing stock in the *group 1* states. This result is in direct contradiction to the expectations of the stakeholders. Given the standard errors of the coefficients, we cannot be certain that the differences between the *group 1* and *group 2* states are statistically significant. To this end, we propose a simple hypothesis test.

The claim of the stakeholders is that the policies of the *group 1* states actively encourage the installation of electric equipment and that the policies of the *group 2* states actively encourage the installation of natural gas equipment. The results in Table 9 seem to imply that the differences between the *group 1* and *group 2* states are negligible. We can test the hypothesis by deriving parameters that are linear combinations of the coefficients β_{C1}, β_{C2}, β_{C1t} and β_{C2t}. The difference β_{C1}-β_{C2} represents the difference in the initial effect of the energy code in the *group 1* and *group 2* states. The difference β_{C1t}-β_{C2t} represents the difference in the effect of post-code housing in the *group 1* and *group 2* states when the housing stock is 100 percent code-compliant. The sum $\beta_{C1}+0.25\beta_{C1t}$ is the effect of the energy code on the share of electricity in the *group 1* states after 25 percent of the housing in those states complies with the energy code. Therefore, $\beta_{C1}+0.25\beta_{C1t}-\beta_{C2}-0.25\beta_{C2t}$ is the difference in the fuel share in the *group 1* and *group 2* states after 25 percent of the housing stock in both groups complies with the energy code.

Table 10 contains the values of the derived parameters and their standard errors. The t-ratio is the ratio of the value of the parameter to its standard error. The t-probability is the probability of the event that the derived parameter is equal to zero. The parameter corresponding to the difference in the initial effect of the energy code is positive, but its magnitude, when compared to its standard error, is so small as to be indistinguishable from zero. The parameter that describes the overall effect of the energy code is negative and has the comparatively large magnitude of 0.211. However, recall that this parameter corresponds to the situation in which all of the housing stock in the states has been replaced. Its standard error is also relatively large with respect to its value. It is more instructive to consider the parameter that represents the situation in which 25 percent of the housing stock is replaced. The difference between *group 1* and *group 2* states is -4.4 percent: the average share of electricity in the *group 1* states is 4.4 percent less than the average share in the *group 2* states after 25 percent of the housing stock complies with the code. Considering its sign and standard error, this parameter may not be interpreted in a way to suggest that the policies of the *group 2* states favor natural gas over electricity (or that the policies of the *group 1* states favor electricity over natural gas.) To summarize, the claims that the policies of either the *group 1* or *group 2* states have resulted in a bias for or against electricity or natural gas are unsupported.

Derived parameter	Value	Standard Error	t-ratio	t-probability
$\beta_1 - \beta_2$	0.008	0.017	0.490	0.312
$\beta_{1t} - \beta_{2t}$	-0.211	0.138	-1.524	0.064
$\beta_{C1}+0.25\beta_{C1t}-\beta_{C2}-0.25\beta_{C2t}$	-0.044	0.023	-1.943	0.026

Table 10. Values of derived parameters for fuel share identification with standard error and t values.

Criticisms of the model we have chosen to identify are omitted variables, serial correlation of residuals, heteroskedadicity, multicollinearity and mis-specification among others. We have checked for the existence of each of these issues. Consider omitted variables. The model has 8 parameters and 1248 data points and an adjusted R^2 of 0.844. It is doubtful that omitted variable bias affects the results. Nevertheless, we have tested the model with climate as an independent variable (represented by heating degree-days.) The results do not change.

Since we use panel time-series data for the identification of the model, problems associated with serial correlation of the residuals and heteroskedadicity of the disturbance process can be significant. The presence of both serial correlation and heteroskedadicity does not bias the parameter identification, but it does change the standard errors of the parameters. A test for heteroskedadicity among the groups of states is visual inspection of the residual plotted against estimated value of the electricity share for the three groups of states. Figure 15 is a scatter plot of these values. For the *no code* and *group 1* states, the distribution of the residual values is relatively uniform across the estimated values.

The *group 2* state residual distribution is considerably more sparse and shows the residuals to be distributed by state, indicating the presence of serial correlation for this group of states. A Cook-Weisberg test for heteroskedadicity among the three groups of states gives a χ^2 value of 12.2 for the hypothesis that the variance in the three groups is constant. The probability corresponding to this value is 0.002 leading us to reject the hypothesis. As mentioned before, the presence of serial correlation and heteroskedadicity does not affect the interpretation of the model, but it is important to take steps to correct for these factors. The fourth column of Table 9 contains standard errors that correct for the presence of serial correlation and heteroskedadicity: we cannot use these standard errors for hypothesis testing as presented in Table 10. However, since the corrected standard errors are uniformly larger than the uncorrected standard errors, we reach the same conclusion regarding the effect of the energy code in the *group 1* and *group 2* states on the share of electricity: that the difference in the electricity share between the *group 1* and *group 2* states is unrelated to the energy code.

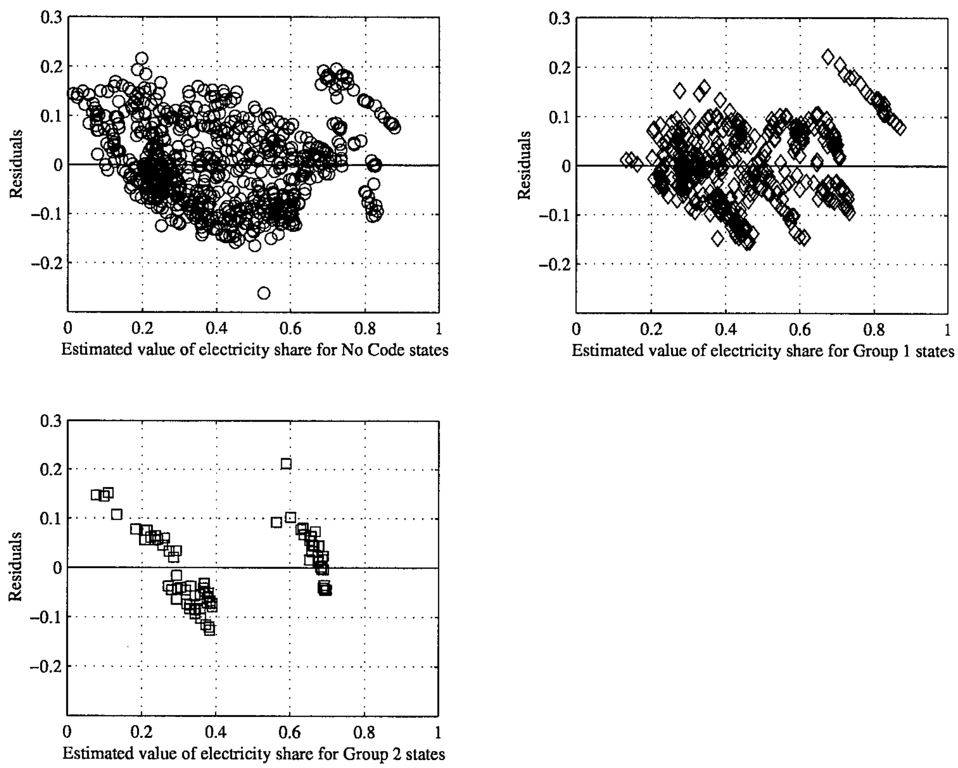

Figure 15. Scatter plot of residuals versus estimated values for the fuel share model.

The correlation coefficients of the data for each independent variable with respect to all other independent variables serves as a test for multicollinearity. The magnitude of the correlation coefficient is less than 0.51 for all pairs of variables with the exception of the data used to identify β_{Ci} and β_{Cit}, i=1,2. The values of the correlation coefficients of the data for these variables is 0.71 (i=1) and 0.82 (i=2). Most certainly the data corresponding to these parameters is linearly independent and does not result in a degenerate parameter identification.

As in most model identifications, mis-specification of the model is a primary concern. With respect to this model, the fuel share in any state is a function of the fuels that are used in that state. An alternative modeling methodology would be to model energy consumption by fuel type in the residential sector; the fuel share would be a consequence of the detailed energy consumption model. Such a methodology would be more complete than the one presented above, but would also be significantly more complicated and require a research effort far beyond that employed here. Furthermore, it would not necessarily answer the question at hand: is there a difference in the share of natural gas and electricity used in the residential sector between states with site-based energy codes and energy codes that differentiate between fuels? The model that we have identified succinctly answers this question.

The natural gas and electric industries do not consider the fraction of natural gas or electricity in the residential sector the market share of the fuel. The industries prefer to use the fraction of homes with a natural gas or electric appliance as the market share. Since the DOE *Household Energy Consumption and Expenditures* is a triennial publication, both the AGA and the EEI have to rely upon their own surveys to update their data in the intervening years. For example, the AGA publishes the *Market Intelligence Quarterly* for its members. For the residential analysis, the market share of every major appliance is tabulated for homes in each census region. We have chosen not to use the marketing data because we have been unable to verify its accuracy.

There is no doubt, however, that states utilize natural gas and electricity very differently. The DOE-EIA reported energy consumption characteristics at the state level for the four most populous states: California, Florida, New York and Texas (DOE-EIA 1995). These four states have a diversity of residential energy efficiency codes and we can illustrate some of the differences in the marketplace using these states as examples. The fitted lines in Figure 5 indicate the average rate of change of fuel share since code implementation; for Texas, the fitted line indicates the change in fuel share between 1985 and 1995.

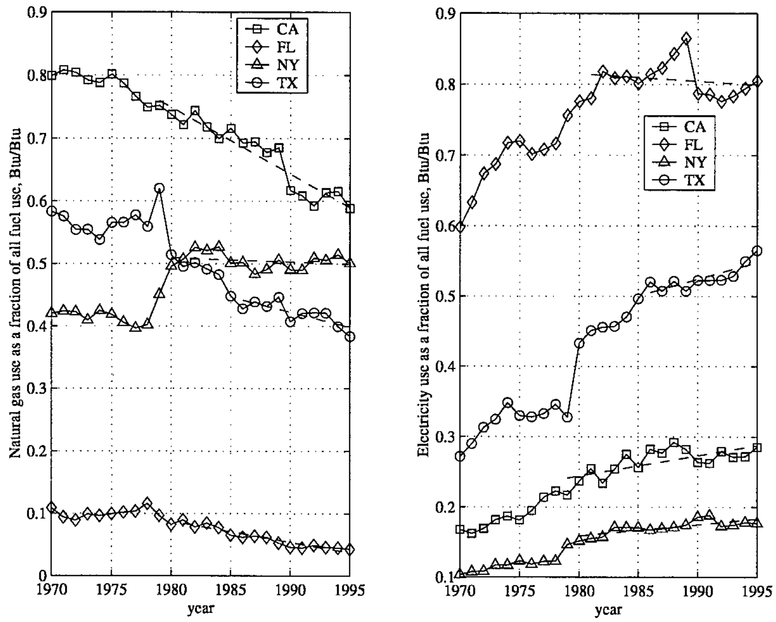

Figure 16. The share of natural gas and electricity in California, Florida, New York and Texas from 1970 to 1995.

State	Year of residential energy code implementation	Rate of change of share of natural gas, 1/year	Rate of change of share of electricity, 1/year
California	1978	-0.0069	0.0018
Florida	1982	-0.0010	0.0019
New York	1979	-0.0003	0.0012
Texas	N/A	-0.0018	0.0026

Table 11. Average rate of fuel share change since code implementation to 1995.

Table 11 contains the information on the rate of change of the fuel share in the states. It is in California, the only state with a source-based energy code, in which the share of natural gas in the residential sector is falling most rapidly. While the performance requirements of Title 24 make it very difficult to install an electric resistance water heater in California, other electric loads are compensating for the loss. The four states have qualitatively the same behavior despite their distributions of end uses and variations in energy codes: the share of natural gas in the residential sector is falling and the share of electricity in the residential sector is rising. The trend may be a function of gains in gas equipment efficiency and the concurrent penetration of additional electric loads in the home. Differences in the fraction of a fuel used for a particular appliance exist and vary from state to state and the variation may be due to the structure of the residential energy code (or absence of a code). When the fraction of natural gas or electricity used in the residential sector is compared across states, however, there is weak evidence that suggests that the fuel share in a state be related to the residential energy code.

3. Energy efficiency behavior modeling and analysis

The annual per capita energy consumption within the states is a function of a number of factors in addition to the presence of an energy code: energy cost, climate, the penetration of certain appliances, the population density and local usage patterns are five possibly significant factors.[15] To partially compensate for these factors, our analysis of the effectiveness of residential energy codes will rely upon relative changes in per capita energy consumption within a state to benchmark code effectiveness, rather than absolute consumption. To begin the analysis, we calculate the rate of change of energy consumption and the percentage change in energy consumption in each state. The results of the calculations appear in Table 12 through Table 14. The rate of change of energy consumption is the slope of the line that best describes (in the least squares sense) the rate of change of per capita energy consumption in each state from the year of code implementation (or from 1985 for the *no code* states) to 1995. The change in energy consumption is the percent change in per capita energy consumption from the average over the years 1970 through 1978 to the average over the years 1988 through 1995. We use the years 1970 through 1978 as a baseline: these years correspond to the beginning of the energy crises and mark the era of greatest per capita energy use.

[15] All calculations with respect to energy consumption in the states use the total source energy (on a Btu basis) consumed in the residential sector in each of the states.

State	Year of residential energy code implementation	Average annual rate of change of per capita energy consumption calculated from the year of energy code implementation to 1995, 10^6 Btu per capita per year.	Percent change in per capita energy consumption from 1970-1978 average to 1988 to 1995 average.
AR	1979	0.4079	-0.9
CT	1979	0.8993	9.8
FL	1980	0.9796	17.5
GA	1978	0.8705	20.0
IA	1978	-0.0531	0.9
ID	1990	-1.2227	1.6
IN	1979	0.3690	-1.9
KY	1982	1.2847	21.1
MA	1975	-0.1566	-12.8
MD	1981	0.9096	17.6
ME	1989	1.8202	-13.9
MI	1985	0.7085	-2.8
MN	1976	0.1271	-3.3
MS	1980	1.1119	6.4
MT	1978	-0.0775	1.2
NE	1980	0.9949	13.5
NC	1978	0.2384	-1.2
NH	1979	0.6845	-21.5
NJ	1976	0.1680	-3.7
NM	1978	0.2541	-6.9
NV	1978	-0.3190	-9.9
OH	1979	0.3369	-3.7
PA	1986	0.6166	0.3
RI	1977	0.5009	-5.5
SC	1979	1.0201	22.1
TN	1978	0.4604	5.2
UT	1978	-0.8715	-13.2
VA	1973	0.5639	15.0
WV	1989	1.5083	16.1
WY	1977	0.4180	-1.3

Table 12. Average annual rate of change in per capita energy consumption and percent change in per capita energy consumption for *group 1* states.

State	Year of residential energy code implementation	Average annual rate of change of per capita energy consumption calculated from the year of energy code implementation to 1995, 10^6 Btu per capita per year.	Percent change in per capita energy consumption from 1970-1978 average to 1988 to 1995 average.
CA	1978	-0.4853	-19.2
NY	1979	0.4964	-3.5
OR	1975	-0.0908	-6.2
WA	1986	-0.2670	-5.4
WI	1978	0.1177	-4.6

Table 13. Average annual rate of change in per capita energy consumption and percent change in per capita energy consumption for *group 2* states.

State	Average annual rate of change of per capita energy consumption calculated from 1985 to 1995, 10^6 Btu per capita per year.	Percent change in per capita energy consumption from 1970-1978 average to 1988 to 1995 average.
AL	1.1236	12.3
AZ	0.2670	4.1
CO	0.6085	0.0
DE	0.8458	6.3
IL	0.7471	-5.1
KS	0.6646	-7.5
LA	0.7038	11.9
MO	0.9201	7.5
ND	1.3568	29.7
OK	0.6847	1.4
SD	0.3412	9.6
TX	0.0719	3.9
VT	2.3597	-19.4

Table 14. Average annual rate of change in per capita energy consumption and percent change in per capita energy consumption for *no code* states.

Figure 17 and Figure 18 summarize the data in Table 12 through Table 14. Recall from Figure 6 that the real price of energy has been declining since 1984; reductions in energy consumption in that interval, therefore, are taking place without the economic motivator of price. From this data, we hypothesize that that the *group 2* states are quantifiably distinct from the *no code* states in reductions in residential per capita energy consumption and the *group 1* states are not. The remainder of the analysis tests the robustness of the hypothesis against exogenous economic factors that may influence energy consumption patterns. The analysis concerns only the percent change in per capita energy consumption.

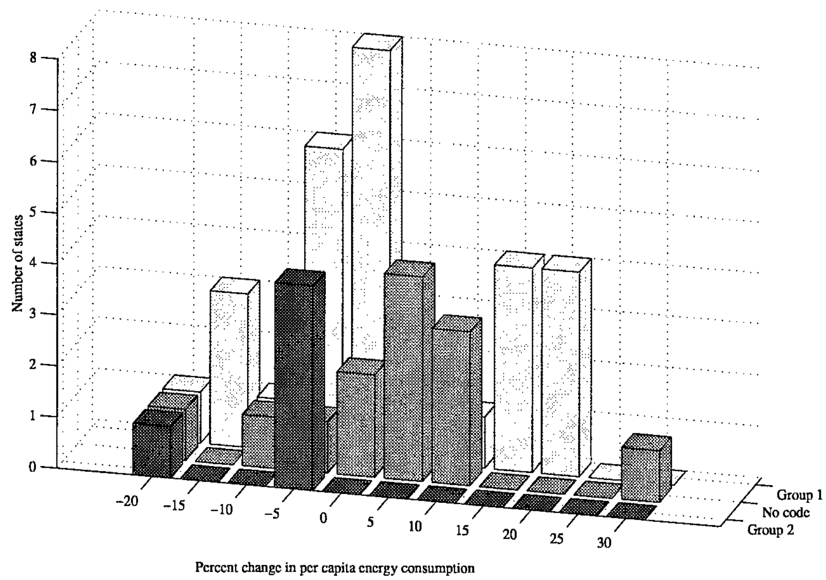

Figure 17. A histogram of the percent change in per capita energy consumption from the 1970 to 1978 average to the 1988 to 1995 average for the three groups of states.

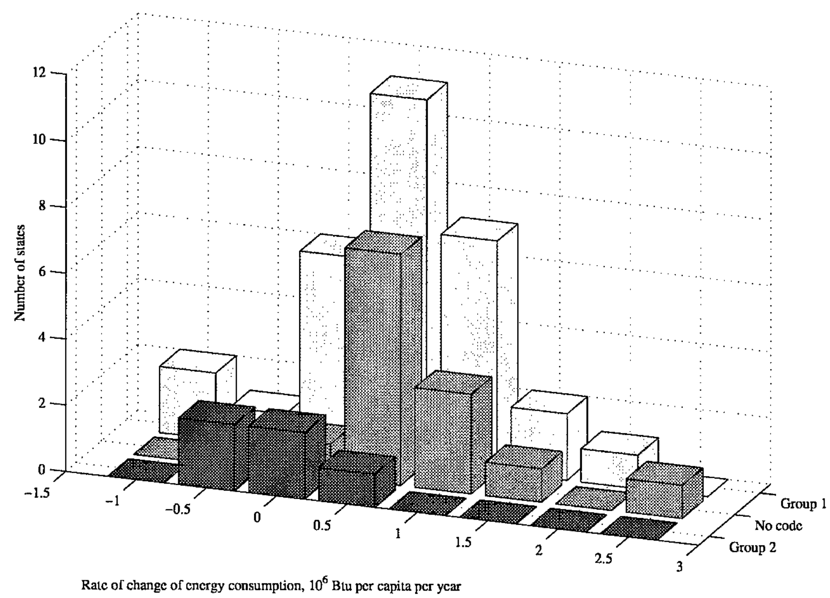

Figure 18. A histogram of the rate of change in energy consumption since code implementation or from 1985 for states with no energy codes for the three groups of states.

The simple statistical model that we propose to test our hypothesis – regarding the effectiveness of code stringency – depends upon price, previous energy use, the fraction of new housing, and the fraction of new multiunit housing in the states. Figure 19 is a set of scatter plots of the data. The upper-left plot in Figure 19 displays the percentage change in energy consumption against the average energy consumption from 1970 to

1978. On average, the states with low energy consumption from 1970 to 1978 have had greater percent increases in energy consumption. Energy is a consumer good and we expect changes in energy consumption to reflect price and changes in price. The upper right and lower left plots in Figure 19 show the change in energy consumption versus energy price and change in energy price respectively. The plots in Figure 19 do not support this conjecture; states with group 1 energy codes are especially erratic in their behavior. Finally, states should be self-controlling with respect to energy use. Those states with the most per capita energy consumption in the 1970s should be the states with the most per capita energy consumption today. The average energy consumption in the 1970s and 1990s by state is plotted in the lower right of Figure 19.

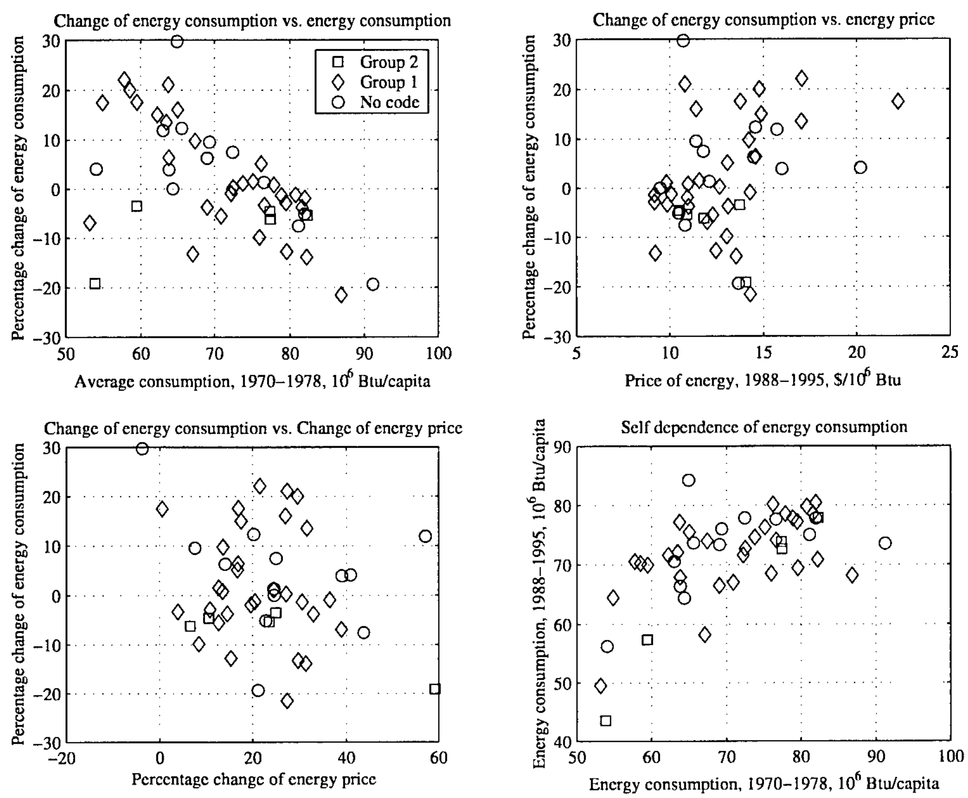

Figure 19. Scatter plots of changes in energy consumption versus energy consumption and price in the three groups of states.

To confirm the robustness of our observation on the distribution of percent changes in per capita energy consumption by state group to perturbations with respect to economic effects, we perform a simple least squares identification using the data in Figure 19 and data on post-code housing. The identification quantifies proportional changes in the dependent variable with respect to proportional changes in the independent variable. Consider the following model for the proportional change in per capita energy consumption,

$$\ln\left(\frac{E_{88-95}}{E_{70-78}}\right) = \alpha + \beta \ln E_{70-78} + \gamma \ln\left(\frac{P_{88-95}}{P_{70-78}}\right) + \delta \ln P_{88-95} + \varepsilon \ln H_{88-95} + \eta \ln M_{88-95} + \phi_1 D_1 + \phi_2 D_2 ,$$

where $E_{x\text{-}y}$ denotes the average energy use per capita over the years x to y, $P_{x\text{-}y}$ denotes the average price of energy over the years x to y, $H_{x\text{-}y}$ denotes the average fraction of housing in years x to y constructed after code implementation, $M_{x\text{-}y}$ denotes the average fraction of the post-code housing that is multiunit, and D_i are the dummy variables: *1* for the *group 1* states and *2* for the *group 2* states. We expect the change in energy use to be negatively correlated to the change in the energy price, the price of energy and the presence of energy codes; from Figure 19, we do not expect the current price of energy to have a significant effect on the change in per capita energy consumption. The results of the identification appear in Table 15.

The results confirm that the decline in per capita energy consumption in a state can be attributed in part to the type of energy code. As we expected, the change in per capita energy consumption is negatively correlated to percent changes in energy price. It is positively correlated to the price of energy; the parameter, however, is statistically insignificant and confirms the observation from Figure 19. It is negatively correlated to the percentage of post-code housing and positively correlated to the percentage of new multiunit housing; neither of these parameters is statistically significant. The insignificance with respect to multiunit housing is partially corroborated by Jaffe and Stavins (1995), who in an analysis of energy efficiency in homes noted no statistical correlation of insulation and energy efficiency measures with the percentage of a state population that lives in urban areas (and presumably in multiunit housing.) The percent change in per capita energy use is also negatively correlated to the presence of either type of energy code. The value of the parameter corresponding to the *group 1* states is negative, but not significant. The value of the parameter corresponding to the *group 2* states is negative and has a greater magnitude than that of the corresponding to the *group 1* states and is statistically significant. The results confirm our intuition: the *group 2* states outperform their peers with respect to changes in per capita energy consumption. California, New Mexico and Utah are the outliers of the analysis: for these three states, the actual negative percent change in energy consumption is greater than that predicted by the model.

Independent variable	Coefficient	Standard error
Constant	2.12	0.56
Average energy use 1970 to 1978	-0.53	0.10
Percentage change in energy price	-0.43	0.12
Price of energy, 1988-1995	0.06	0.08
Percentage of new housing	-0.08	0.03
Percentage of new multiunit housing	0.03	0.06
Group 1 states	-0.03	0.03
Group 2 states	-0.13	0.04
Adjusted R^2		0.50

Table 15. Regression coefficients and standard errors for model representing the percent change in per capita energy consumption.

The simplicity of the model and the small size of the data do not warrant deep scrutiny of the results. Therefore, although our analysis verifies that the *group 2* states are statistically different from the *no code* states with respect to reductions in residential per capita energy consumption and the *group 1* states are not, the results should be interpreted with attention to the caveats that appear in Section III.3.

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